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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

INVENTOR(S)

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☐ *Additional inventors are being named on the ___separately numbered sheets attached hereto.*

TITLE OF THE INVENTION (280 characters max)

PREDICTION OF SHALLOW DRILLING HAZARDS USING SEISMIC REFRACTION DATA

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- [ ] Applicant claims small entity status. See 37 CFR 1.27.
- [X] A check or money order is enclosed to cover the filing fees
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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

- [X] No.
- [ ] Yes, the name of the U.S. Government agency and the Government contract number are: ____________

Respectfully submitted,

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Date February 26, 2004

REGISTRATION NO. 25,928 (*if appropriate*)

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PREDICTION OF SHALLOW DRILLING HAZARDS USING SEISMIC REFRACTION DATA

Field of the Invention

The invention relates to a method of utilizing three-dimensional land or ocean bottom cable (OBC) seismic data to predict the location of shallow drilling hazards such as karsting and voids in near subsurface formations.

Background of the Invention

Shallow drilling hazards in carbonate formations are well known to present potential problems in exploration and developmental drilling and can represent a significant risk to the exploitation of hydrocarbons. Shallow formation carbonates are subject to the presence of groundwater and dissolution, creating void air spaces (caves) of varying and highly irregular dimensions. Some of these voids collapse totally or partially, while others remain intact. If a drill bit and string encounter such a karst feature, there is an immediate loss of circulating fluid, and there also can be a bit drop through the void space of the karst. This can result in the total loss of the well at great expense.

Production three-dimensional seismic data is normally gathered and employed for the imaging of seismic reflection data for targeted and prospective reservoirs. This data is then analyzed by seismic interpreters, sometimes using three-dimensional visualization techniques, to interpret and map these reservoirs for the purpose of locating areas of trapped hydrocarbons for subsequent exploitation by drilling.

The oil industry has for some years recognized the desirability, if not the necessity of locating and avoiding shallow drilling hazards. These hazards to drilling are very time-

consuming to traverse with the drill bit and therefore expensive, and represent a potential danger to drilling crews. Most industry efforts to solve the problem that have been published and, in some cases patented, are associated with exploration in marine offshore environments. Shallow subsurface voids and the potential for mudslides can endanger the drilling operation. Further problems can be caused by shipwrecks and other man-made obstructions. It is also possible for localized zones of natural gas under pressure to exist in very shallow rock strata that would pose both a drilling risk of blowout, as well as a structural risk to the platform.

In marine exploration and development programs today, it is common for both corporations and governments to require the acquisition of a seismic hazard survey that is usually two dimensional for a planned drilling location. This requirement is particularly appropriate where large and expensive drilling platforms must be built and positioned over an area to be drilled. The sea floor must be able to sustain the forces of drilling equipment and operations. Should failure occur, it would result in the potential loss of the platform and associated equipment, risk the lives of operating personnel and the loss of millions of dollars in capital investment. The environmental risks are obvious and significant. These marine hazards can be detected by the utilization of streamer seismic data and by the careful processing of the signal to preserve the phase and relative amplitudes of the reflected arrivals in the shallow section below the water bottom. Drilling hazards can often be detected using a method such as that described in USP 5,555,531, that employs three-dimensional seismic data in a marine environment.

To date, all known efforts to locate these karsted features in seismic land data in carbonate environments have relied on the use of seismic reflection data. The results have been limited or poor.

Previous attempts to detect shallow hazards include the so-called seismic-while-

drilling (SWD) method. The goal was to gain the ability to look ahead of the bit while drilling is underway using the descending drill bit as an acoustic source, and in conjunction with surface-located receivers. For example, in USP 6,480,118 a seismic-while-drilling (SWD) method is described that generates seismic data useful for looking ahead of the drill bit which is employed as the acoustic source. The processed look ahead data is used to maximize the drilling penetration rate based on the selection of more effective drill bits. The method purports to be useful in minimizing the risks of encountering unanticipated drilling hazards. The SWD method suffers the drawback that the well is already positioned and drilling is underway, so that the well may be placed in a disadvantageous location, without any practical alternative but to keep drilling.

A second approach has been to employ reflection seismic data in an effort to map these karsted features. To date, this method has not been entirely successful. The reason for the lack of success is the relatively poor sampling of reflections in the very shallow portion of the seismic prestack record. Absent a very high-resolution survey, which for large drilling programs would be prohibitive in terms of time and cost, there is no apparent method using reflection data can be improved sufficiently to reliably identify the shallow hazards.

Other proposals and efforts to employ different types of data, such as ground-penetrating radar (GPR) have not proved practical, since penetration into the karsted subsurface is inadequate.

For example, the method disclosed in USP 4,924,449 employs reflected energy from a highly specific location using a positional sub-surface transducer array. While useful in marine environments, it is not useful in a land setting.

A survey of the patent literature has not revealed a satisfactory solution to the problem.

USP 6,593,746 describes a method for radio-imaging underground structures for coal beds, with subsequent analysis performed using Full-Wave Inversion Code (FWIC). It can be used in mining operations where transmitters and receivers are placed in the passageways of mines, conditions which are not present in oil and gas exploration operation.

USP 6,501,703 describes a method utilizing first arrivals of seismic waves that are used to calculate and correct for time statics.

USP 5,757,723 describes a method for seismic multiple suppression using an inverse-scattering method for reflection and transmission data only.

USP 6,473,696 describes a method for obtaining and using seismic velocity information for the determination of fluid pressures for use in the analysis of fluid flow in reservoirs, basin modeling and fault analysis.

USP 5,671,136 describes a process that removes the refraction information present in the data. and then uses the seismic reflection data to define hydrocarbon-bearing strata, aquifers and potential drilling and mining hazards, utilizing visualization. .

A method specifically directed toward the detection of drilling hazards in marine environments using high-resolution three-dimensional seismic data based on reflection data that has been processed to retain broad bandwidth is disclosed in USP 5,555,531. It employs reflection seismic data analysis identifying mud slides, shipwrecks, salt structures, mud flows and fluid expulsion features in deeper water environments, i.e., water depths of 800 feet or greater.

Seismic data is produced when a seismic compressional acoustic waveform is produced at the surface by a source such as dynamite or a mechanical source, e.g., a device such as that sold under the trademark VibroSeis. The waveform spreads as a spherical wave propagation into the earth where it is both reflected and transmitted through rock strata in the

subsurface. The reflected energy returns to the earth's surface as reflected waves, where it is recorded by receivers, such as geophones, that have been positioned on the surface at predetermined points displaced from the source.

When a source generates a waveform, it spreads in depth (Z direction) and laterally (X and Y directions). When a waveform spreads at a certain angle (the critical angle), it bends or refracts, and travels along a rock interface rather then through it. This portion of the wave energy is returned to the receivers as a refracted wave.

As noted above, relatively shallow rock strata, karsts can exist. Geologically, they are produced by the dissolution of rock, i.e., the chemical reaction between carbonates and water. These subterranean caves or voids, can be highly irregular in shape and size. In the case of larger karsts or as a result of increases in overburden forces, these voids cannot support the weight of the rock strata above and they collapse on themselves. These collapses can be unconsolidated, that is, there remain a series of much smaller karsts; or they can be consolidated, for example, as a result of further collapses.

When a refracted wave travels along a relatively homogeneous rock interface, the waveform will do so at a specific velocity and travel back to the receivers on the surface where they are recorded at a certain time, frequency and amplitude over a predetermined sampling interval. However, when the refracted waveform encounters a void or a heterogeneity in its path, the waveform is disturbed and the resultant amplitude and/or frequency of the wave returned to the receivers is abnormal.

The situation is very different on land, however, although the risks and dangers of near-surface hazards are similar. These include, but are not limited to, the loss of the borehole, damage to well structures and equipment, blow-outs, environmental damage and lost drilling fluid circulation. The adverse effects of an unexpected encounter with shallow

drilling hazards can be elucidated as follows:

1. Lost Circulation of Drilling Fluids

   A. Any sudden loss of the circulating drilling fluid incurs both a monetary loss and an increase in mechanical risk to the equipment.

   B. If hazards could be identified prior to drilling, the drilling engineers could plan the mud injection program accordingly, which at present they are unable to do. This would result in improved use of material and monetary savings during drilling.

2. Unexpected Drill Bit Drops

   A. A drop through a void or karst can result in mechanical damage to the drill string and bit.

   B. The drill string can become stuck in the hole, resulting in the loss of the borehole, in which case the entire well must be redrilled at enormous costs in time and money.

3. Personnel Safety Issues

   A. If shallow karsted zones are unknown to drilling personnel, a bit drop can be hazardous to workers on the drilling platform floor.

   B. Under some circumstances, the rig itself can be damaged if the string drops through the drilling floor.

The problem with a land environment, particularly one characterized by shallow carbonates and anhydrites, is that using reflection data will not work as it does in the marine environment. The reasons for this include:

1. In normally-acquired seismic data, the survey and dimensions are designed for deeper targets which possess commercial potential for hydrocarbon accumulation. These surveys are therefore not sampled adequately in the spatial domain closest to the earth's surface.

2. Reflection land seismic information in the shallow subsurface (above about 1000 feet) will be muted in the processing of the data. Later, the data recorded at each time sample will be corrected for normal moveout and stacked to suppress random noise. The problem is that, in these shallow zones, there is usually inadequate sampling in offset to statistically cancel out the noise.

As used herein, the terms reflected waves, reflection data, reflected energy and reflectors can be used interchangeably and synonymously; similarly the terms refracted waves, refracted energy, refraction energy and refractions are to be understood as equivalent terms.

Three-dimensional seismic surveys are designed primarily to image final drilling objectives ranging from 5000 feet to more than 18,000 feet below the earth's surface. These three-dimensional surveys are not designed for shallow target resolution.

Current practice in the industry is to conduct shallow hazard marine surveys using reflection data searching for shallow gas-charged zones that would present a danger to the location and structural integrity of off-shore drilling platforms. These surveys are two-dimensional seismic profiles and they are routinely performed today due to the economies of scale involved. A two-dimensional seismic profile is several orders of magnitude less expensive than the capital cost of a deep-water drilling platform and the marine survey can significantly reduce the risk of damage to, or loss of the platform.

To date, industry efforts have attempted to employ reflection two-dimensional data to

locate shallow hazards in much the same way as marine two-dimensional surveys have been used. However, it has been found that onshore hazard surveys are more problematic, particularly in shallow carbonate sequences due to near-surface effects and the environmental noise contamination of the seismic data.

Summary of the Invention

The method of the invention employs the refraction information recorded during conventional three-dimensional production seismic surveys. The identifiable refractors are separated out and processed to obtain the advantage of the increased spatial sampling. Each refractor, in essence, is processed in a mini-three-dimensional volume, limited in both offset ranges and in time. Each of these "mini-volumes", when processed, is analyzed utilizing a commercially-available three-dimensional visualization software program. Each refractor's time position is correlated to its associated reflection, and this information in time and depth is retained, along with an assessment of the anticipated presence or severity of the karsted features.

The method of the present invention departs from the conventional use of reflection seismic data and instead employs the refraction data that is recorded, but conventionally discarded. This greatly enhances spatial sampling. The near-surface effects on each refracted wave arrival are preferably addressed independently, and following additional processing steps, utilizing commercially available software, each refractor is visualized for the presence of karst and other potentially hazardous features.

For these and other reasons, the present invention employs refraction arrivals, where the sampling is much improved, so as to effectively cancel out random noise. The improvement in the signal-to-noise ratio permits the analysis of the refraction information.

Further, as this invention seeks to accurately detect the presence of karsted features such as subsurface voids or caves, refracted waves are ideally suited to this since they propagate along the very rock strata of interest. The use of refraction arrivals with targeted processing of these waveforms in a land environment forms the basis of the method of the invention.

This method of the invention disregards the reflection data entirely and focuses instead on refracted waves in the near surface. The method of the invention targets the source of potential difficulty and dangers involved in drilling for hydrocarbons in carbonate formations where karsting and unconsolidated collapses can occur. The method provides data (1) to alert the drilling engineers to the presence of these hazards; and (2) to permit the siting of wells in the most advantageous locations to avoid any shallow subsurface hazards.

The method of the invention has the advantages of enhancing the economy and safety of drilling in hydrocarbon exploration and recovery by using elements of pre-existing seismic data that are conventionally discarded or muted, processing it in a novel manner and presenting it for interpretation in a form that facilitates identification of karsts and other shallow drilling hazards.

This invention provides a novel process that uses oil exploration technologies in a different manner for a different and specific purpose, e.g., identifying potential drilling problems in the shallow sections and zones where hazards often exist. The analytical tools employed in this novel process are known to those of ordinary skill in the seismic processing and interpretation art, but the process of the invention has not previously been identified or applied by those of ordinary skill in either of these fields,

The primary use of seismic refraction data in the prior art has been for the resolution of time statics caused by spatial velocity variations in the near surface through a variety of well known methods, including tomography. Refraction data are normally discarded for

conventional reflection-based seismic data processing.

By comparison, the use of refraction arrivals provides far superior spatial sampling. In the process of the present invention seismic reflection data is discarded, or muted out, and the refraction data is retained for analysis. It should be noted that this particular aspect of the method of the invention is not merely an improvement on earlier methods, but rather, is fundamentally different in its use of refracted waves and refraction energy.

The data utilized in the process of the invention is advantageously the pre-existing production seismic data that was originally developed to explore for hydrocarbon accumulations. However, the method of the invention can also be used with seismic refraction surveys, including patches and cross-spreads.

Processing of the seismic refraction data begins with the identification of the refractor waves, or refractors, and their linear moveout velocities. The refraction data is filtered, time-shifted and corrected for linear moveout (LMO). The filtering can be by time, frequency-wave number filtering or FK, Karhunen-Loewe or KL, and data-driven techniques. These and other filtering techniques are well known in the industry and are considered standard techniques.

Each refractor is then separated. Datum or elevation statics are computed and applied, and residual statics are run on each refractor separately. The latter step can be performed before the separation, but superior results have been obtained on separated refractor data. The result of these steps is a plurality of refraction "mini-volumes", which are then binned and stacked. These stacked refraction mini-volumes can then be subjected to post-stack signal processing, if conditions require. Conditions requiring post-stack signal processing can include sever coherent noise generated by surface environmental sources, such as motor vehicles on a highway, pumps, aircraft, pipelines and even strong winds. Suitable

software for use in this phase of the inventive method is available from Paradigm Geophysical under the trademark Focus/Disco.

The refraction mini-volumes are then loaded into a commercially available three-dimensional visualization computer software program application for analysis. Suitable visualization programs are sold under the trademarks VoxelGeo and GeoProbe; other programs include Earth Cube and Geo Viz. These program applications provide the analyst with screen displays from which the analyst plots existing or planned well locations. The mini-volumes are then analyzed separately. The next step is to generate a semblance cube from each refractor mini-cube/volume.

The time image of each refractor will normally vary spatially with time and if the data quality allows, these surfaces can be flattened to allow the analysis to proceed in the time-slice domain with great effect. The effect of time slice analysis is to actually see the karsted features in map view as a function of time. In cases of good overall data quality, this analysis mode provides the seismic interpreters and drilling engineers with estimates of the volume of the karsted void. In the case of an unconsolidated collapsed feature the same visual effect has been observed.

In the event that the data is of relatively poor quality, the analysis can still proceed advantageously by conducting it in X/Y-space, using inlines and cross-lines, or traverses chosen by the analyst.

The basic approach to the method of the invention is to analyze each refractor where data from existing wells showed no events in their drilling histories of lost circulation, bit drops, or other such problems. These points will show an undisturbed refractor amplitude/frequency/semblance response. The same analysis is conducted for problem wells in order to establish a simple and straight-forward calibration of the data. The

aforementioned semblance volumes are employed for the purpose of confirming observations seen on the amplitude/time minivolumes. In the case of very poor quality data, the semblance volumes can be very useful in the performing analysis.

Proposed well sites are then plotted in the visualization application and the corresponding refractor amplitude/frequency responses are noted. Depth and/or time correlations with reflection data are then carried out.

The results of these analyses are communicated to the drilling engineers to enable them to make any necessary alterations to the location of planned wells. In the instance of drilling in an established field with fixed well spacings, relocation of the well site may not be possible. In such a case, the drilling engineers can plan the well drilling program with the identified hazards in mind so that appropriate changes can be made to mud composition and weight, drilling rates and other drilling parameters.

From the above description, it will be understood that the novel process employs conventional seismic data in a new way to address the long-standing problem of mechanical drilling risks in shallow depths of less than 3000 feet utilizing the source-to-receiver offset not normally used in the industry for detecting shallow drilling hazards. The method of the invention utilizes refraction information in a new, unexpected and unconventional manner for a new purpose.

In some locations where there are few wells in the geographic area under investigation, calibrating the processed refracted wave seismic data to well histories will not be possible. Noise and static are also factors that are normally encountered, particularly in areas where surface infrastructure is built up, such as highways, pipelines, towns and the like. Under such circumstances where calibration is difficult, the maximum semblance and amplitudes are located, and it is assumed that these are areas of potentially minimal, but not

non-existent, drilling risks. Static and noise factors are foreseeable and their effects are minimized by the use of conventional signal processing techniques that are well known in the art.

As will also be understood by one of ordinary skill in the art, where karsts and unconsolidated collapses are identified in carbonate strata and these hazardous features cannot be avoided due to well spacing constraints, their identification will enable the drilling engineers and staff to plan accordingly to minimize any adverse consequences during drilling operations.

The process of the invention is advantageously employed to identify large karsts and unconsolidated collapsed features in the subsurface prior to drilling and in the selection of well sites that will obviate or minimize the drilling risks of lost circulation. The invention can also be used to identify very shallow, highly-charged gas zones. Further advantages include the drilling engineers with information that enables them to more intelligently and efficiently plan drilling to reduce costs. Finally, by giving the engineers prior warning of these hazards, drilling plans can be altered to enhance the safety profile of drilling through any hazardous zones that cannot otherwise be avoided.

This invention is applicable to the drilling of wells that employ a drill string and bit, including the drilling of wells for hydrocarbons, water wells and observation/injector wells. The invention can be used for onshore or land areas, for transition zones and in shallow water where an ocean bottom cable (OBC) is employed. The invention is useful with any seismic source/receiver configuration or type that is consistent with the above methods, so long as refraction data has been recorded. The operational depth at which the process is applicable is limited only by the recorded offset range in the three-dimensional seismic survey.

Detailed Description of the Invention

The practice of the process of the invention comprehends the following steos:

a. data reformatting to the internal processing format to be used;

b. determination through inspection, measurement and testing of the LMO velocities of each refractor. An alternate technique of static correction which corresponds to an LMO value/function can be applied. This is sometimes useful for spatial interpolation, should the refractor velocities change spatially;

c. application of LMO velocities to each identified refractor arrival, where refractors are separated into three distinct mini-volumes for prestack;

d. statics application to each mini-volume that can include datum, elevation, refraction and/or residual statics, depending upon the geology of the area under investigation and the severity of the shallow subsurface spatial variability.

e. signal processing, including time and frequency domain filtering, application of FK, KL, or other filtering methods, the selection of which depends upon the area of investigation;

f. CMP/CDP binning

g. stacking of each of the prestack refraction mini-volumes;

h. format change for subsequent loading into commercially-available three-dimensional visualization computer program; and

i. optionally, depthing of volumes using commercially-available software applications, either pre- stack or post-stack.

The visualization analysis which forms part of the invention includes the steps of:

j. loading each mini-volume into the software application;

k. computing the semblance volume for each mini-volume;

l. loading of existing and/or planned wells into the application;

m. picking and flattening of each refractor to allow the analysis to proceed in both X/Y/T traverses as well as, in the time-slice domain; and

n. if well data is available, calibrating both seismic and semblance mini-volumes for each refractor to the existing well data.

The process of the invention predicts shallow drilling hazards such as karsting and unconsolidated collapses in carbonate rock strata. These hazards are very costly and dangerous to exploration and development drilling programs. This process requires no specialized high-resolution seismic surveys, but instead uses existing three-dimensional seismic data normally designed for wildcat or reservoir development. It is also a very fast procedure which means that, in addition to the normal seismic product, a second set of data can be quickly given to interpreters and drilling engineers in order to alert them to the presence of shallow drilling hazards. The invention is highly useful in optimizing well placement to avoid such hazards where possible, and when it is not possible, to allow the drilling engineers to modify the drilling plan in contemplation of such hazards in order to minimize risks of loss of equipment and of injury to personnel.

This process is cost-effective, to implement since no specialized software or hardware is required. Normal three-dimensional visualization software that is commercially available from a variety of vendors can be used for the interpretation of data when processed in accordance with the invention.

The benefits of cost savings, enhanced safety for drilling personnel and reduced mechanical drilling risk are achieved with a minimal capital outlay and in a relatively short

time.

I claim:

1. A method for identifying shallow subsurface drilling hazards, such as karsts, voids, unconsolidated discontinuities and partial collapses located below the earth's surface utilizing petroleum exploration seismic survey data prepared for a specified portion of a geological formation containing existing wells, the method comprising the steps of:

a. providing the original seismic data collected for the specified portion of the geological formation;

b. filtering the seismic data to remove or mute the reflection wave data;

c. gathering and retaining the refraction wave data;

d. filtering the seismic refraction wave data by filter means selected from the group consisting of time FK, KL , data driven, and combinations thereof;

e. time-shifting and correcting the filtered data for linear move out (LMO);

f. separating each refraction wave and computing statics selected from datum statics, elevation status and combinations of both;

g. computing residual statics for each refractor wave to provide refraction mini-volumes;

h. binning and stacking the refraction mini-volumes obtained in step (g);

i. loading the data from step (h) into a three-dimensional visualization computer program and operating the program to provide visual displays;

j. generating a semblance cube for each refractor wave mini-cube volume;

k. flattening the time image of each refractor wave and semblance mini-volumes

l. displaying the time-slice domain visually;

m. comparing the mini-volumes visual display from step (k) with historical experiential information derived from actual drilling operations of the existing wells in

the geological formation; and

n. based on the comparison of data and information in step (m), identifying the location, size and relative seveity of any drilling hazards in the specified portion of the formation.

2. The method of claim 1 which includes the further step following step (k) of processing and displaying the data for analysis on the X/Y-space using inlines and cross-lines.

3. The method of claim 1, wherein the computation of datum or elevation statics is completed before the separation of each refractor wave, and residual statics are computed and applied to each refractor mini-volume.

4. The method of claim 1, wherein the seismic refraction data is filtered in step (d) by a method selected on the basis of the refracted wave data.

5. The method of claim 1, wherein the visual displays are printed for comparison.

6. The method of claim 1 which further includes:

o. siting new wells for drilling in areas that are displaced from any drilling hazards identified in step (n).

7. The method of claim 1 which further includes plotting the location of proposed wells in the same visualization program employed in step (i) and computing and storing refractor

amplitude and frequency responses; and computing depth and/or time correlations with original reflection data from step (a).

8. The method of claim 1 in which the analysis is performed for drilling hazards located at about less than four thousand feet below the earth's surface.

9. The method of claim 8, wherein the depth is determined by the design of the original seismic acquisition survey and the maximum recorded offset ranges.

10. A method of processing and displaying hydrocarbon exploration seismic data prepared for a specified portion of a geological formation in order to identify the location of shallow subsurface drilling hazards, the method comprising the steps of:

a. analyzing refracted waves over a processing block;

b. selecting offset ranges and refracted wave velocities;

c. identifying spatial changes;

d. spatially correcting for refractor linear moveout;

e. applying datum statics;

f. applying surface consistent residual statics;

g. applying filtering analysis;

h. separating refractors to separate datasets using offset ranges;

i. applying filtering;

j. applying surface-consistent statics to each dataset;

k binning each dataset separately to CMP and stack;

l. outputing SEGY;

m. loading SEGY outputs into a three-dimension software visualization program;

n. performing quality control analysis and corrections on refractor cubes utilizing program procedures;

o. generating semblance cubes for each dataset;

p. loading pre-existing well-location coordinates or anticipated well bore locations into program of step (m);

q. calibrating each well location against any seismic data that is available;

r. analyzing each well bore path through each refractor dataset to identify drop-outs associated with karsts; and

s. analyzing the semblance cubes against amplitude volumes for consistency.

Abstract

Shallow drilling hazards, such as karsts, caves, voids and unconsolidated discontinuities, that can pose significant risks to exploration and development well drilling operations are detected employing seismic refraction data on which a series of attribute analyses are performed, the resulting data being further processed to provide a three-dimensional visualization. Refracted wave raypaths are highly distorted by encountering a karst feature with the occurrence of backscattering absorption. The resultant energy recorded at the surface receivers is significantly reduced as compared to refracted waves recorded by other receivers where no karsting is present. Multiple refractors are subjected to a relatively simple and rapid processing using commercially available software to track these differences and to map them in the near surface to improve the siting of wells and to alert drilling engineers and crews to the possibility of encountering the hazard.

FIGURE 1

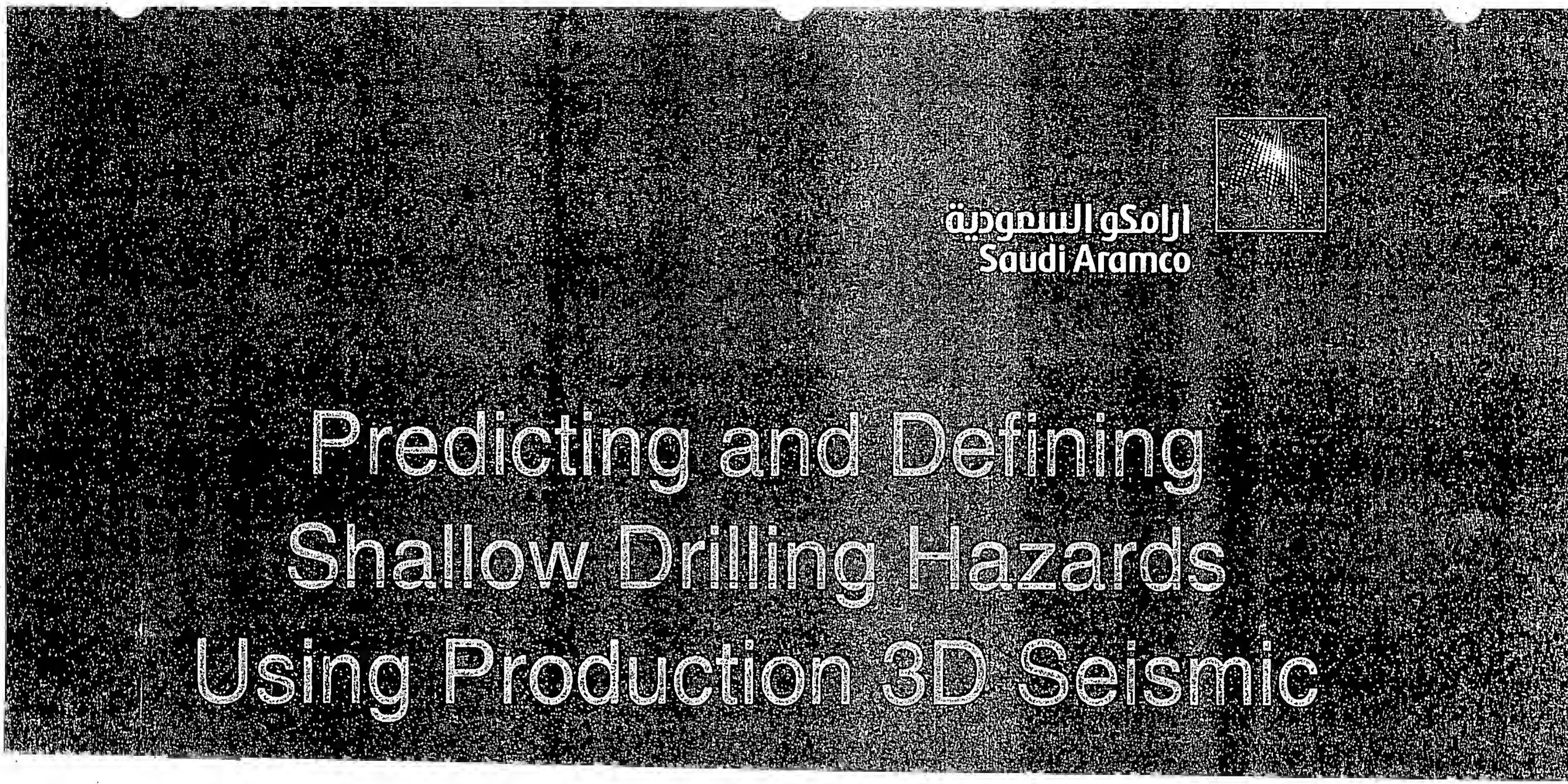
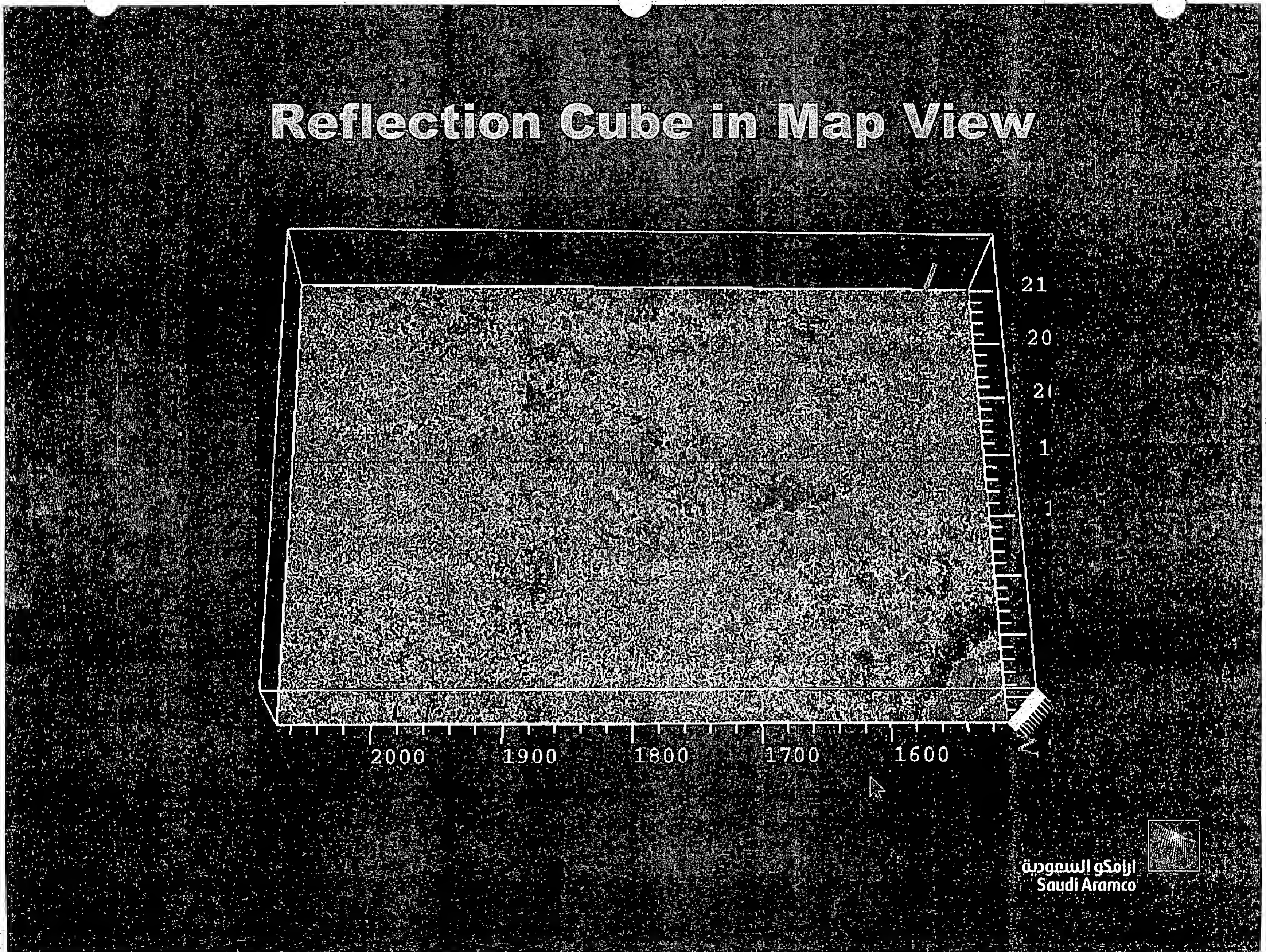

ارامكو السعودية
Saudi Aramco
Predicting and Defining
Shallow Drilling Hazards
Using Production 3D Seismic

Figure 2


Reflection Cube in Map View
21
20
20
1
2000
1900
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1700
1600
N
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Figure 3

Conventional Reflection Seismic (Can You Pick the Hazards On This Data?)

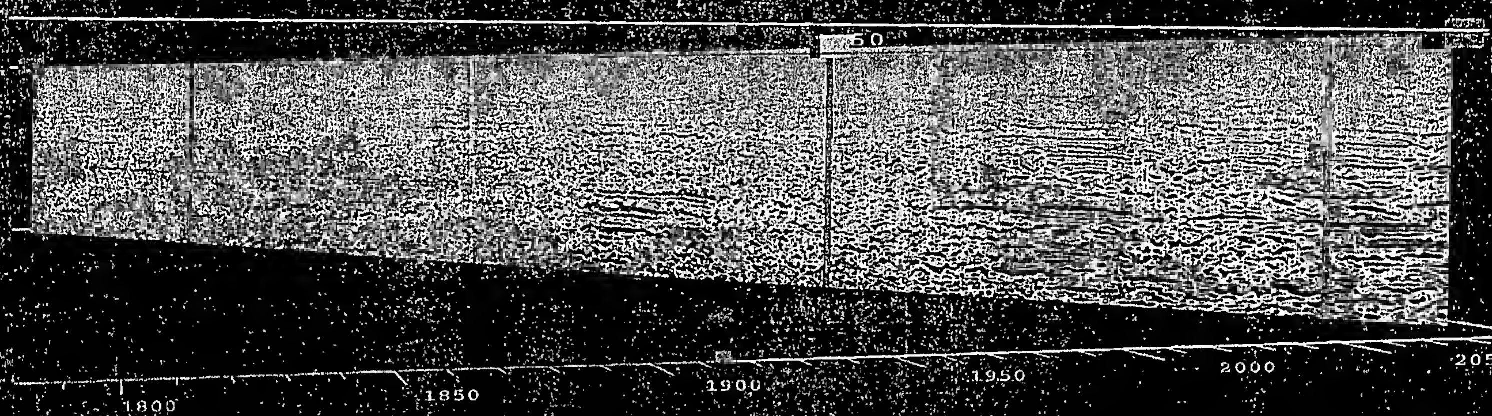

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Figure 4

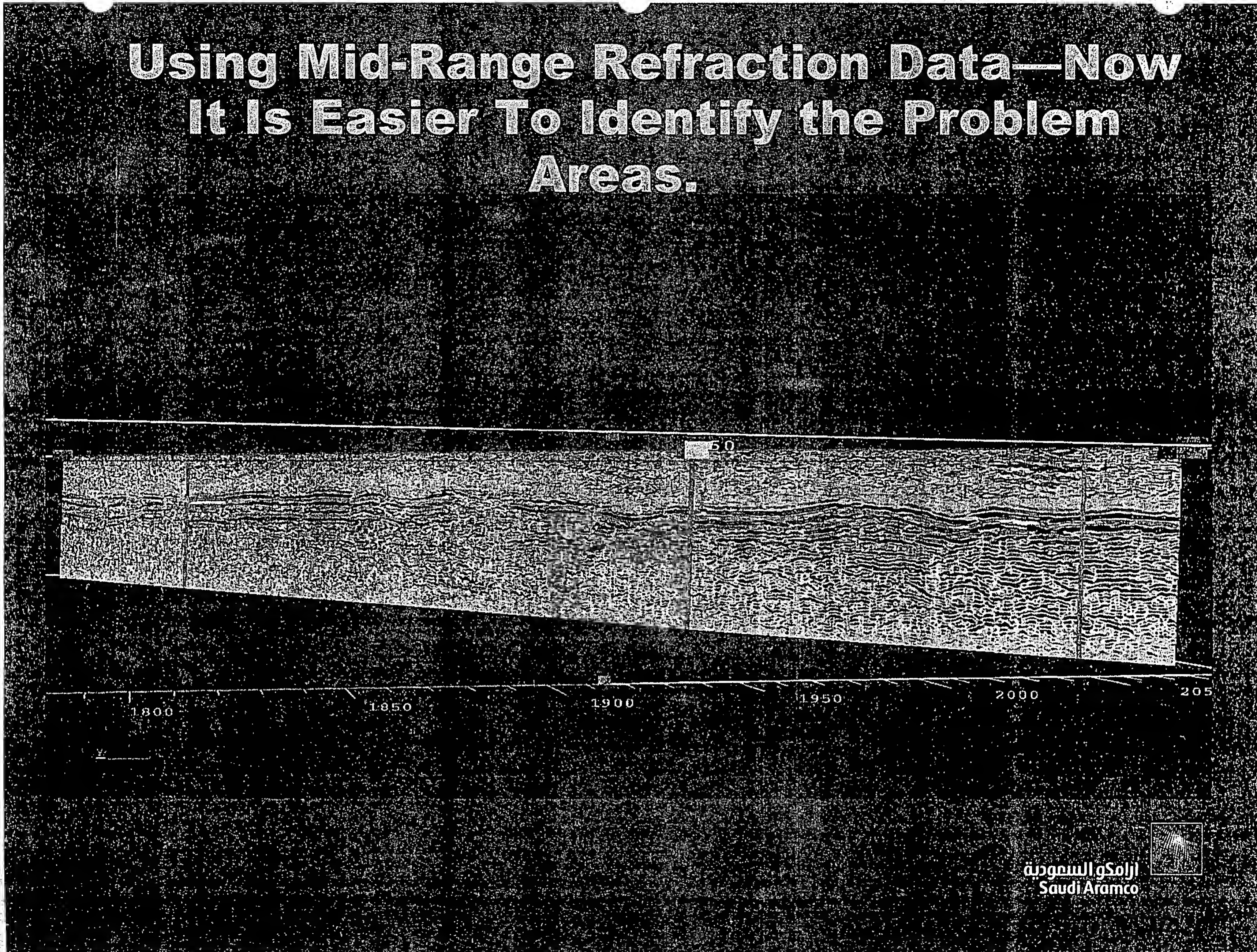
Using Mid-Range Refraction Data—Now It Is Easier To Identify the Problem Areas.
50
1800
1850
1900
1950
2000
205
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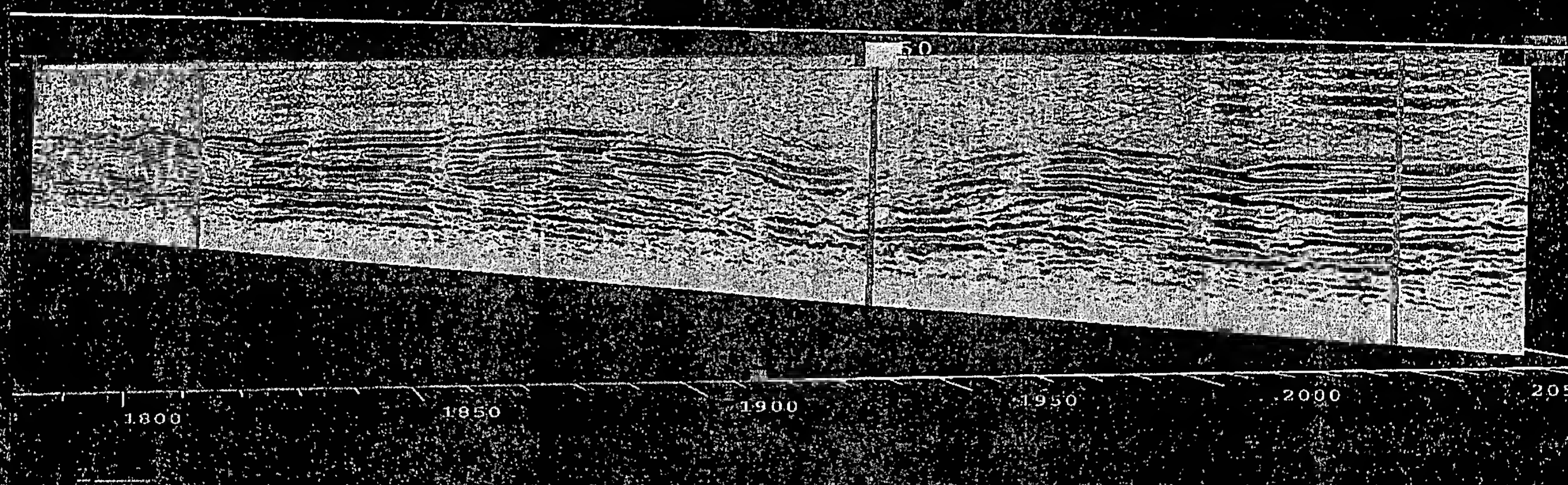
Figure 5

Far Refractor Stack: The Largest Problem Zones are Easily Seen



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HAZARD PROCESSING SEQUENCE

- Sort into signed offset or azimuth.
- Select effective ranges avoiding mode conversion.
- Filter to avoid scalar problems with both ground roll and ambient noise.
- Apply high frequency component static
- Normalize amplitudes by agc
- Select LMO velocity
- Compute and apply residual static
- Stack in CMP

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FIG. 6

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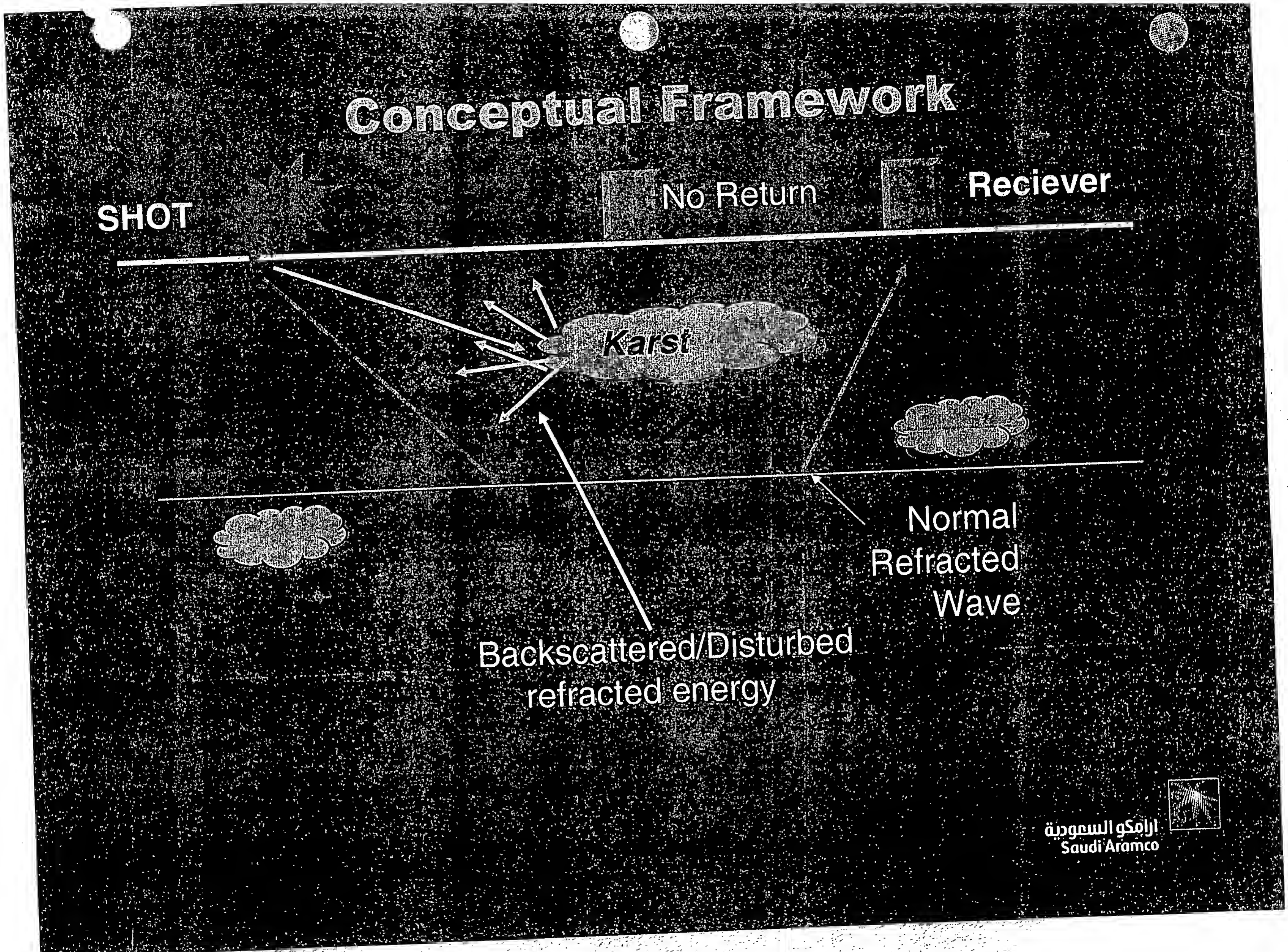
Conceptual Framework
SHOT
No Return
Reciever
Karst
Normal
Refracted
Wave
Backscattered/Disturbed
refracted energy
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FIG 7

02363

Figure 8

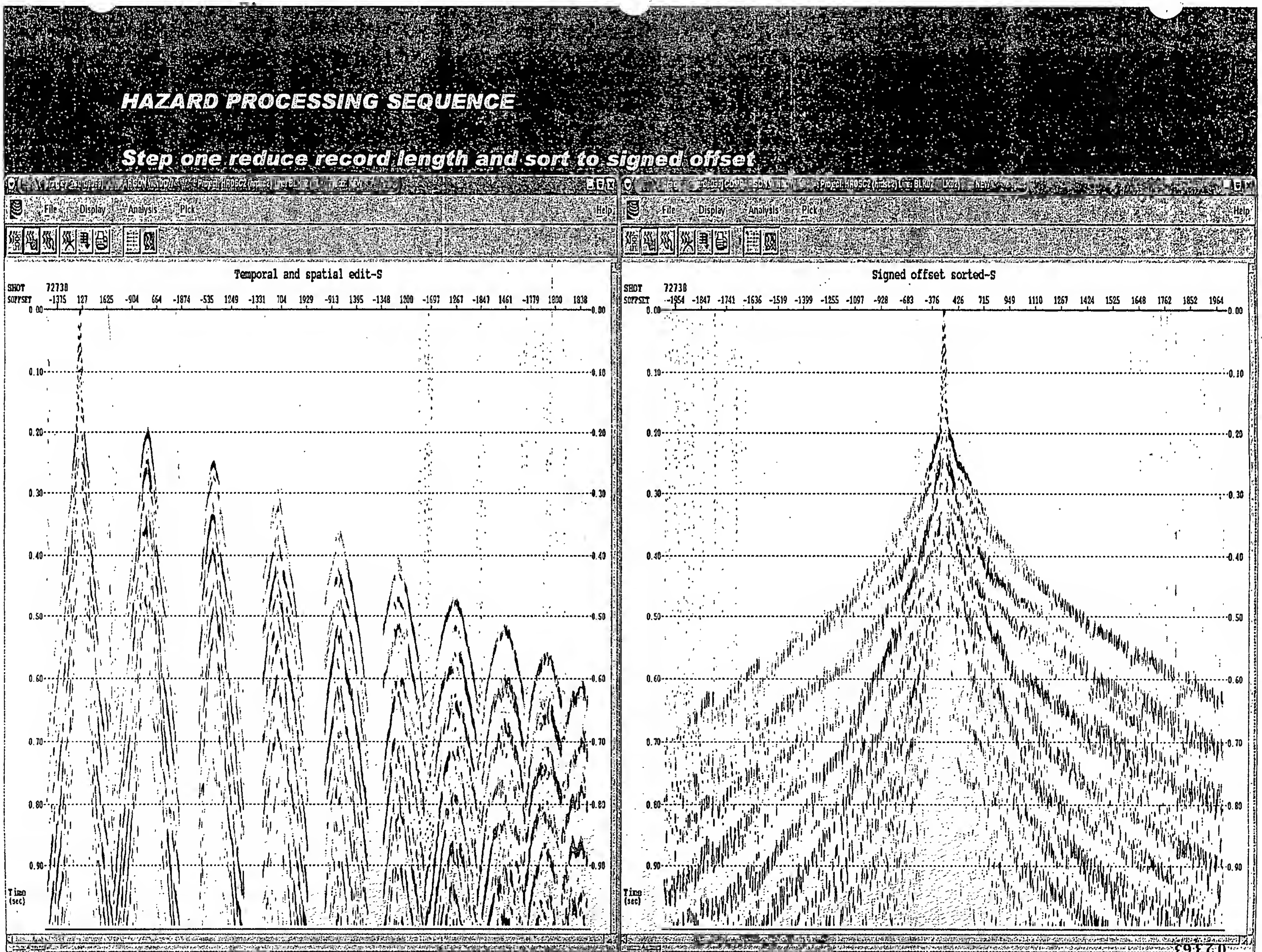
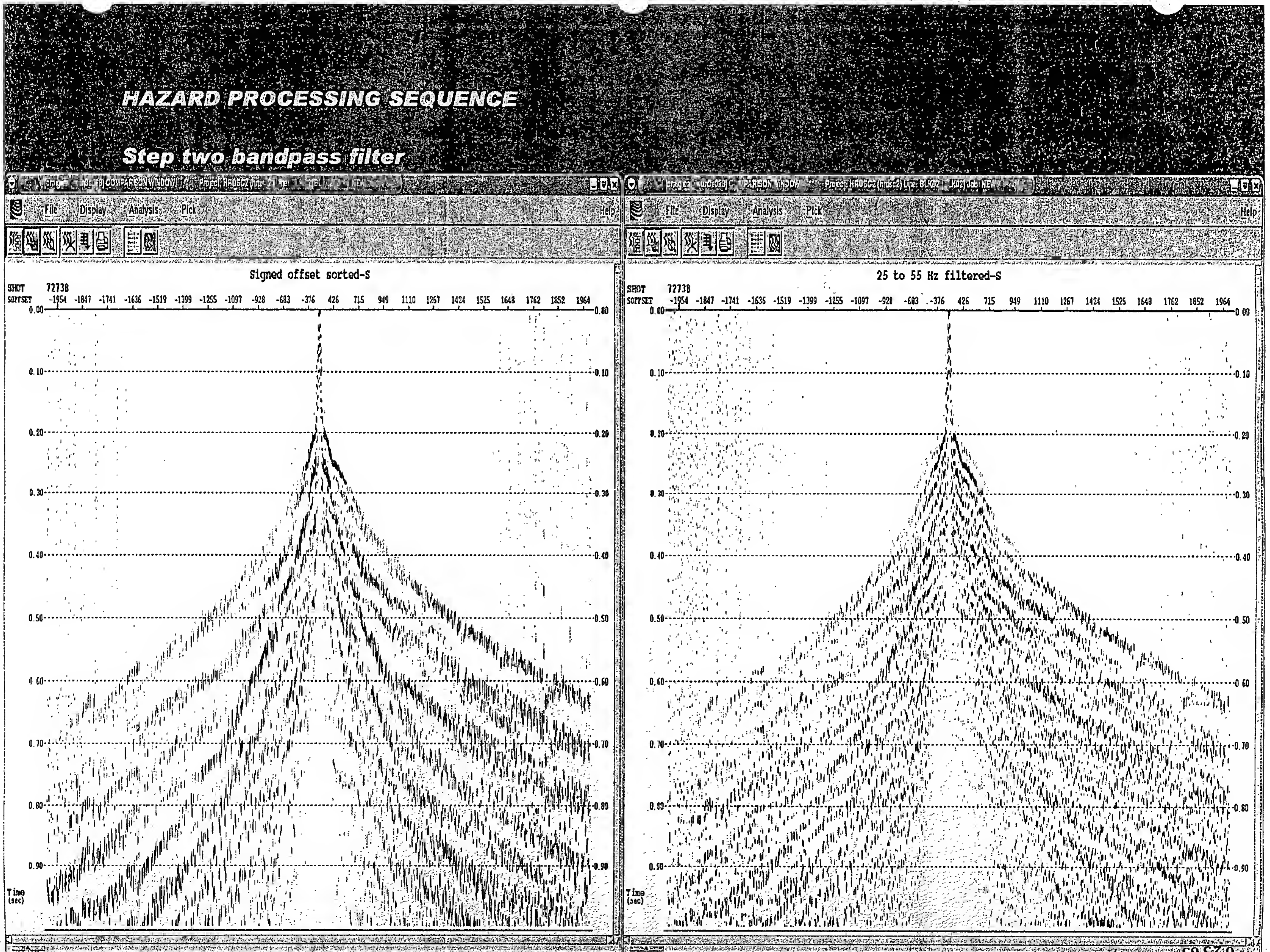
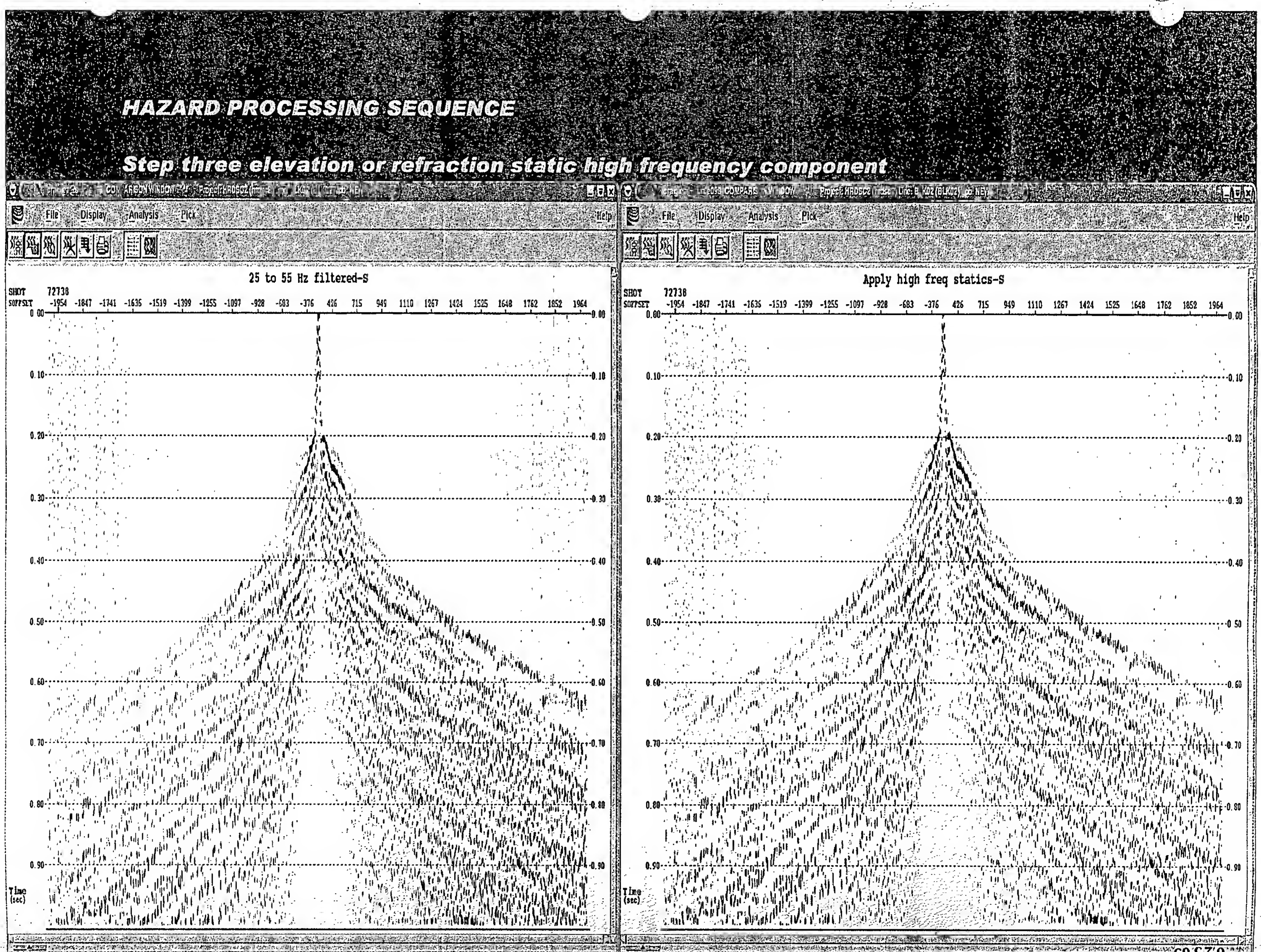

HAZARD PROCESSING SEQUENCE
Step one reduce record length and sort to signed offset
File
Display
Analysis
Pick
Help
Temporal and spatial edit-S
Signed offset sorted-S
SHOT
72738
SOFFSET
Time (sec)

Figure 9



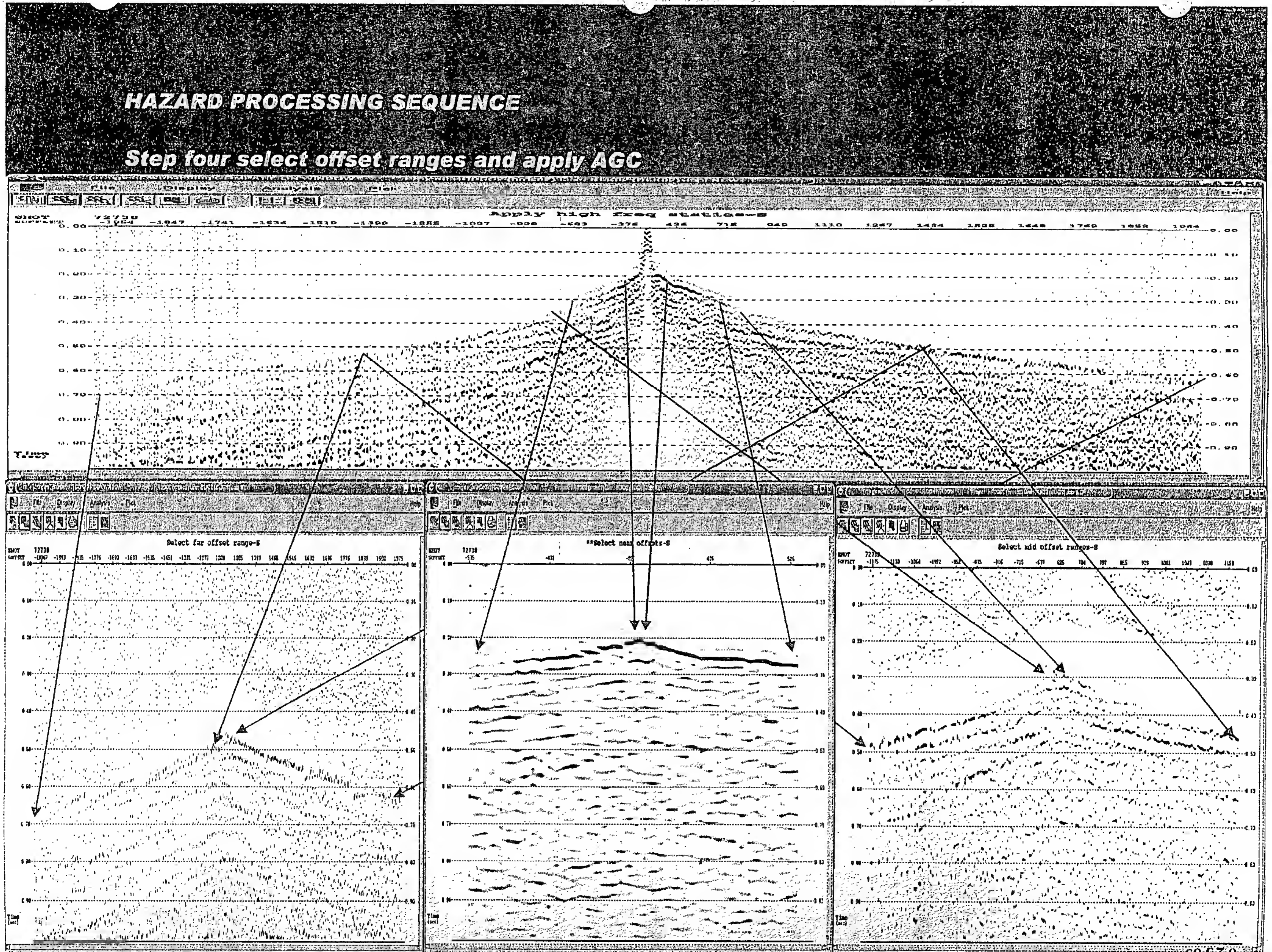
HAZARD PROCESSING SEQUENCE
Step two bandpass filter
File
Display
Analysis
Pick
Help
Signed offset sorted-S
25 to 55 Hz filtered-S
SHOT 72738
SOFFSET
Time (sec)

Figure 10



HAZARD PROCESSING SEQUENCE
Step three elevation or refraction static high frequency component
File
Display
Analysis
Pick
Help
25 to 55 Hz filtered-S
Apply high freq statics-S
SHOT
72738
Time (sec)

Figure 11



023763

Figure 12

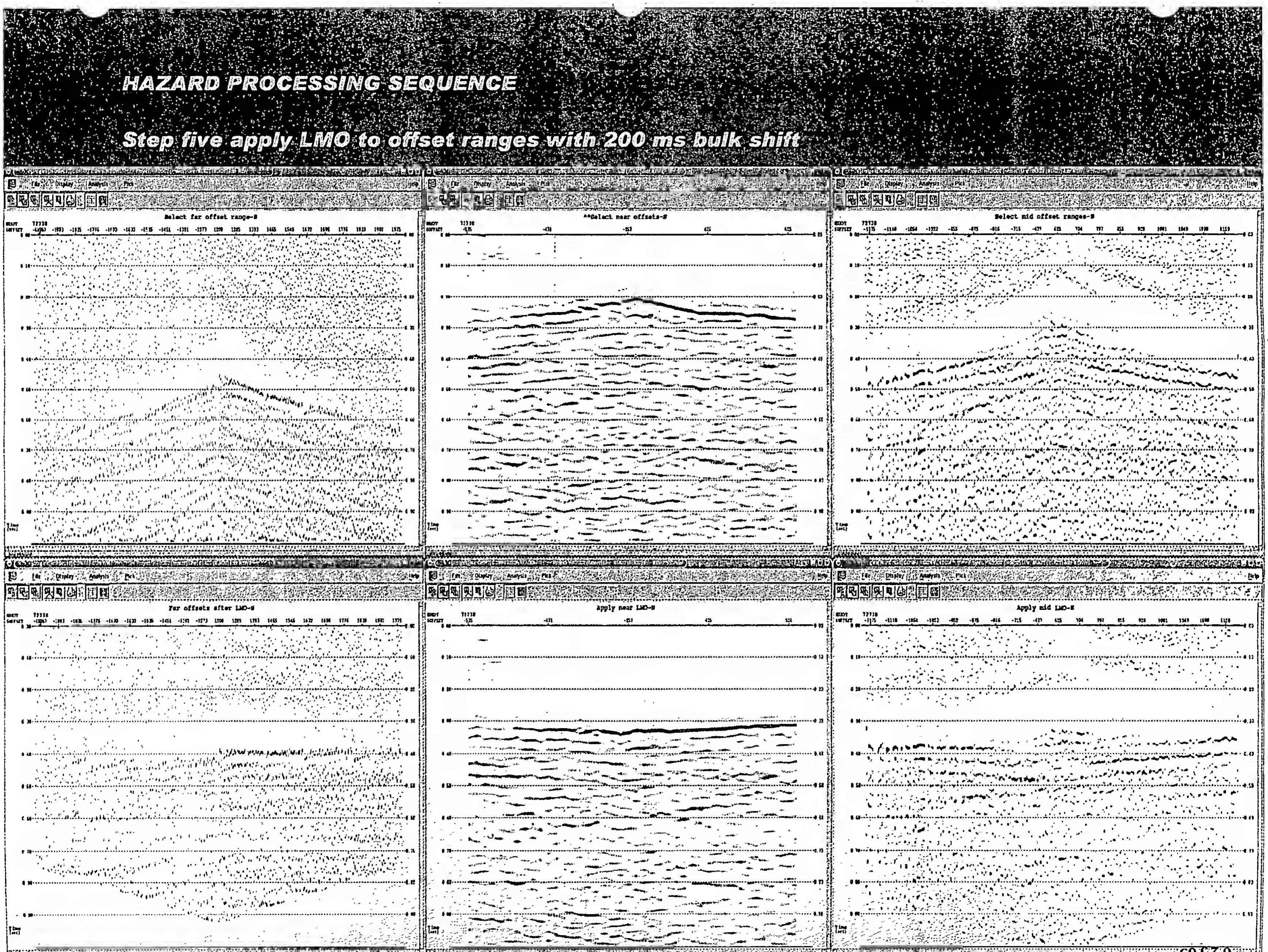

HAZARD PROCESSING SEQUENCE
Step five apply LMO to offset ranges with 200 ms bulk shift
Select far offset range-8
**Select near offsets-8
Select mid offset ranges-8
Far offsets after LMO-8
Apply near LMO-8
Apply mid LMO-8

Figure 13

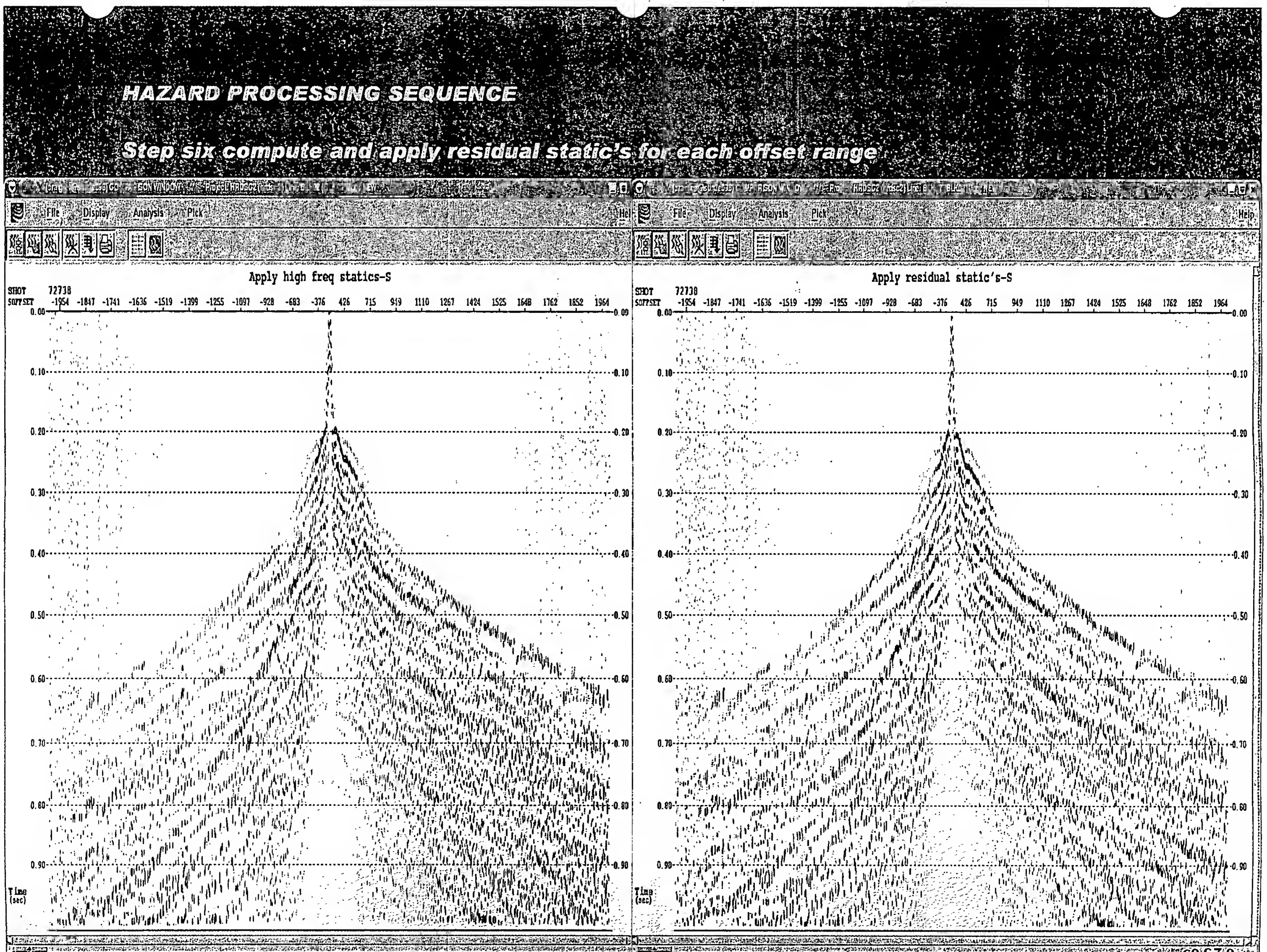

HAZARD PROCESSING SEQUENCE
Step six compute and apply residual static's for each offset range
File Display Analysis Pick Help
Apply high freq statics-S
SHOT 72738
SOFFSET -1954 -1847 -1741 -1636 -1519 -1399 -1255 -1097 -928 -683 -376 426 715 949 1110 1267 1424 1525 1648 1762 1852 1964
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
Time (sec)
Apply residual static's-S
SHOT 72738
SOFFSET -1954 -1847 -1741 -1636 -1519 -1399 -1255 -1097 -928 -683 -376 426 715 949 1110 1267 1424 1525 1648 1762 1852 1964
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
Time (sec)

Figure 14

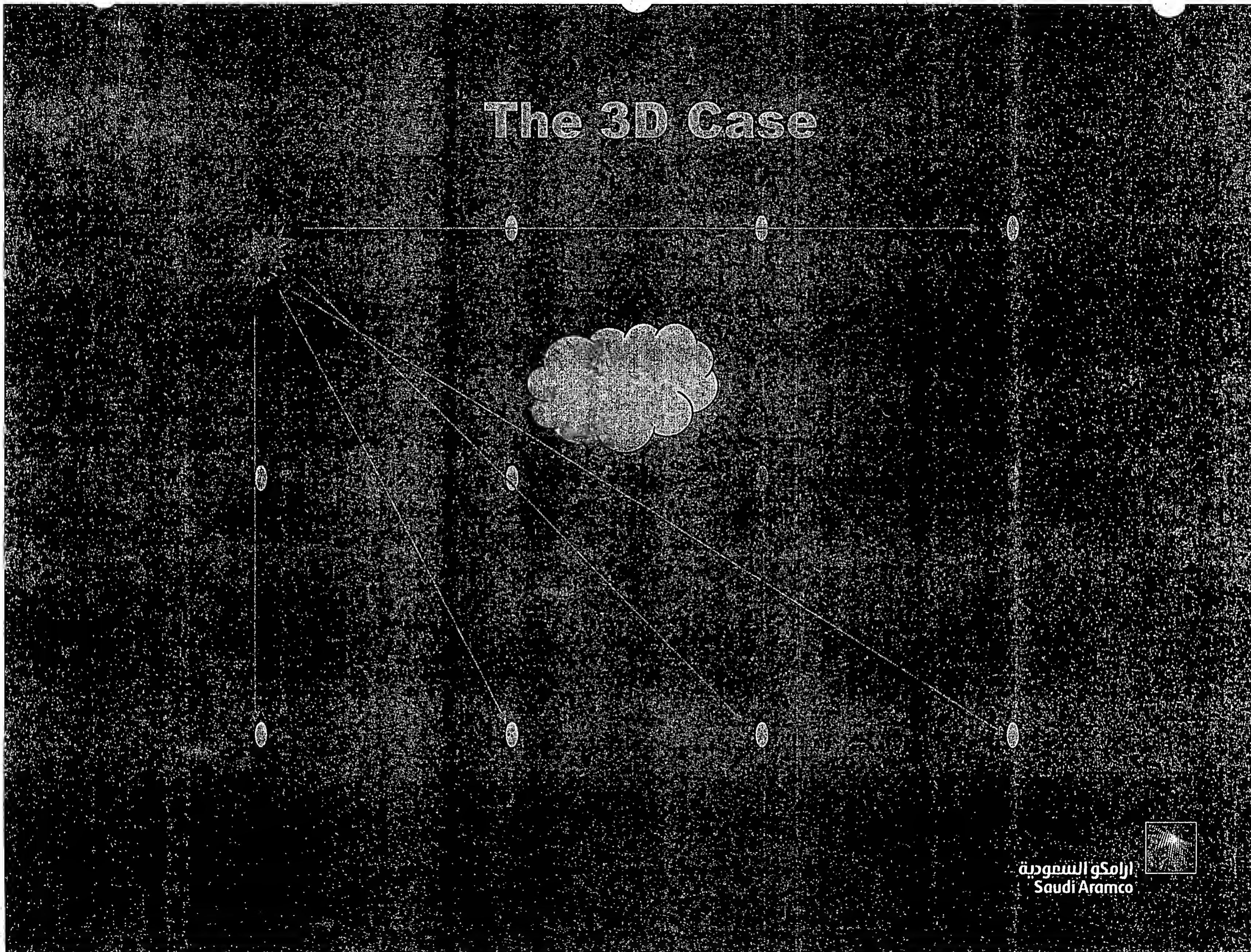


Figure 15

HRDH 950 Well

- Lost Circulation through Aruma.
- Bit stuck, had to twist off.
- Corrective Actions:
  - Cemented zone
  - Redrilled through cement

NOTE: Refraction response over entire drilling island is very poor and future wells will likely encounter similar problems to HRDH 950.

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HRDH 912 Well

- Encountered 100% Circulation Losses in Three Zones:
  - 377 feet
  - 430 feet
  - 510 feet

NOTE: Small losses occurred at deeper depths (2950 and 3840 feet) which are beyond the "far" refractor range we are considering here.

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FIG. 16

HRDH 654 Well

- Encountered 100% Circulation Losses in Two Zones:
  - 435 feet
  - 490 feet

NOTE: Significant losses occurred at deeper depths (3140 and 3258 feet) which are beyond the "far" refractor range we are considering here.

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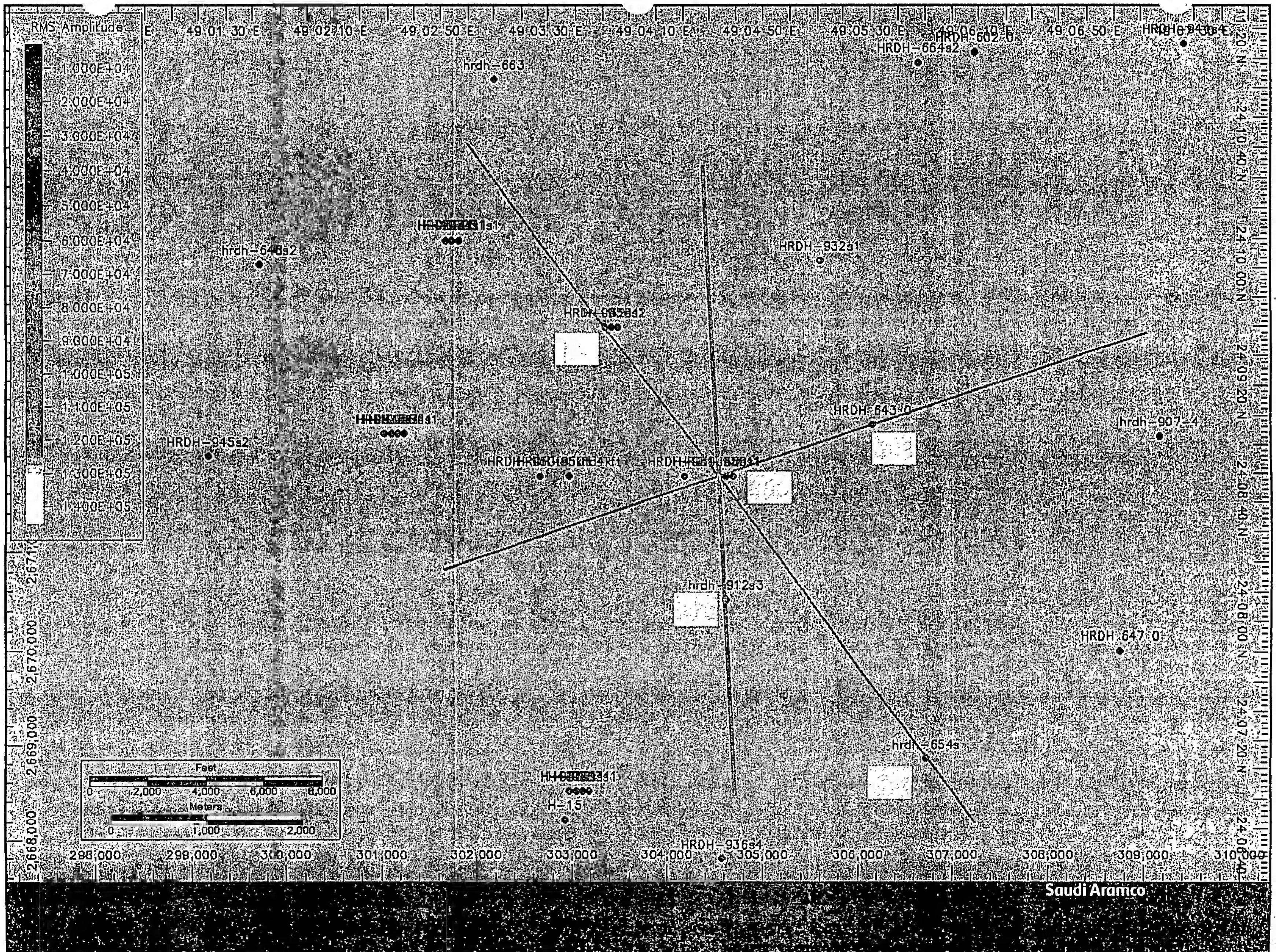
FIG. 17

Figure 18


RMS Amplitude
1.000E+04
2.000E+04
3.000E+04
4.000E+04
5.000E+04
6.000E+04
7.000E+04
8.000E+04
9.000E+04
1.000E+05
1.100E+05
1.200E+05
1.300E+05
1.400E+05
49 01 30 E
49 02 10 E
49 02 50 E
49 03 30 E
49 04 10 E
49 04 50 E
49 05 30 E
49 06 10 E
49 06 50 E
24 10 40 N
24 10 00 N
24 09 20 N
24 08 40 N
24 08 00 N
24 07 20 N
hrdh-663
HRDH-664s2
HRDH-602-0
hrdh-646s2
HRDH-932s1
HRDH-643-0
hrdh-907-4
HRDH-945s2
hrdh-912s3
HRDH-647-0
hrdh-654s
H-15
HRDH-936s4
Feet
0
2,000
4,000
6,000
8,000
Meters
0
1,000
2,000
2,668,000
2,669,000
2,670,000
298,000
299,000
300,000
301,000
302,000
303,000
304,000
305,000
306,000
307,000
308,000
309,000
310,000
Saudi Aramco

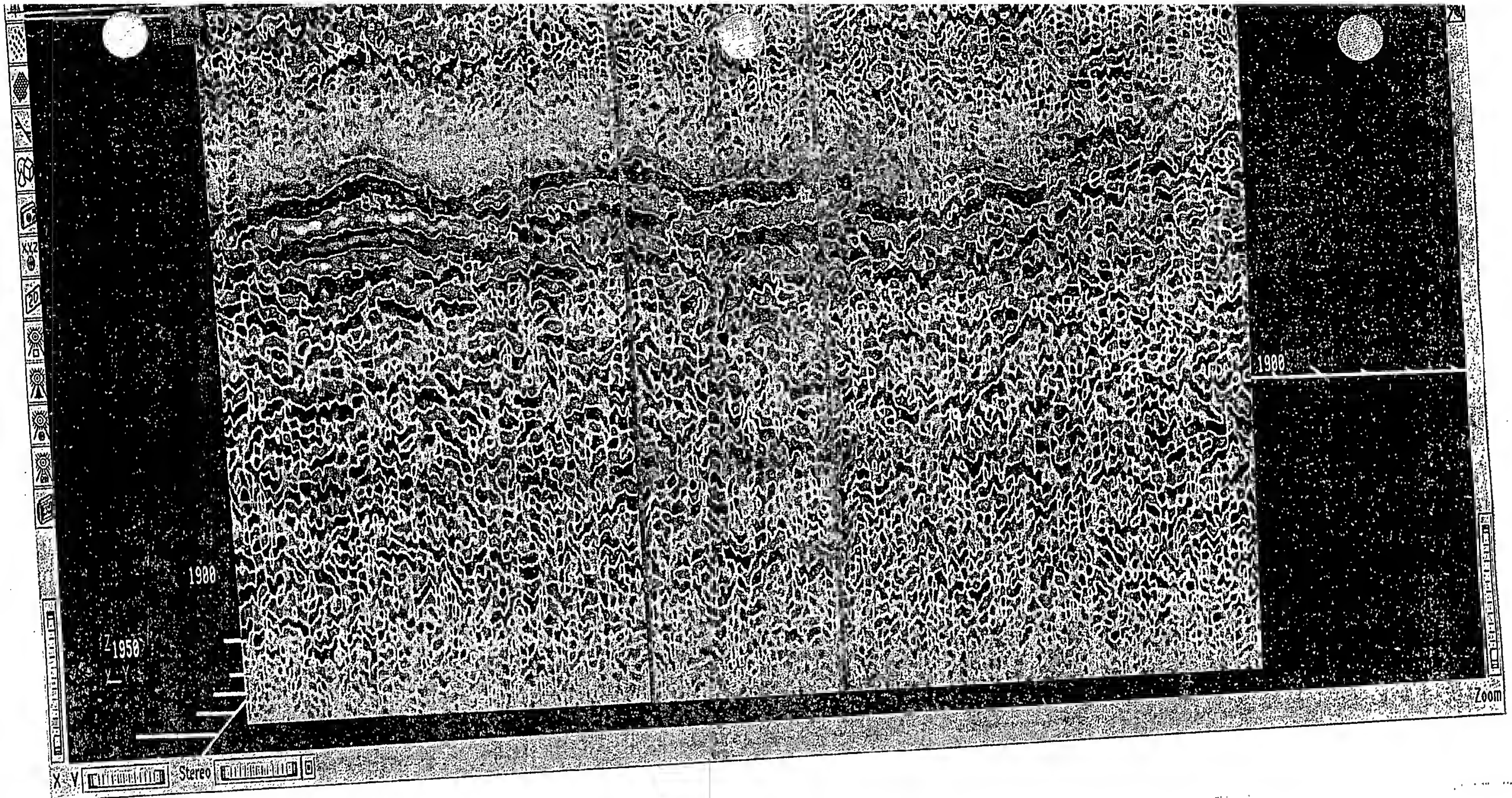


FIG. 19

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Figure 20

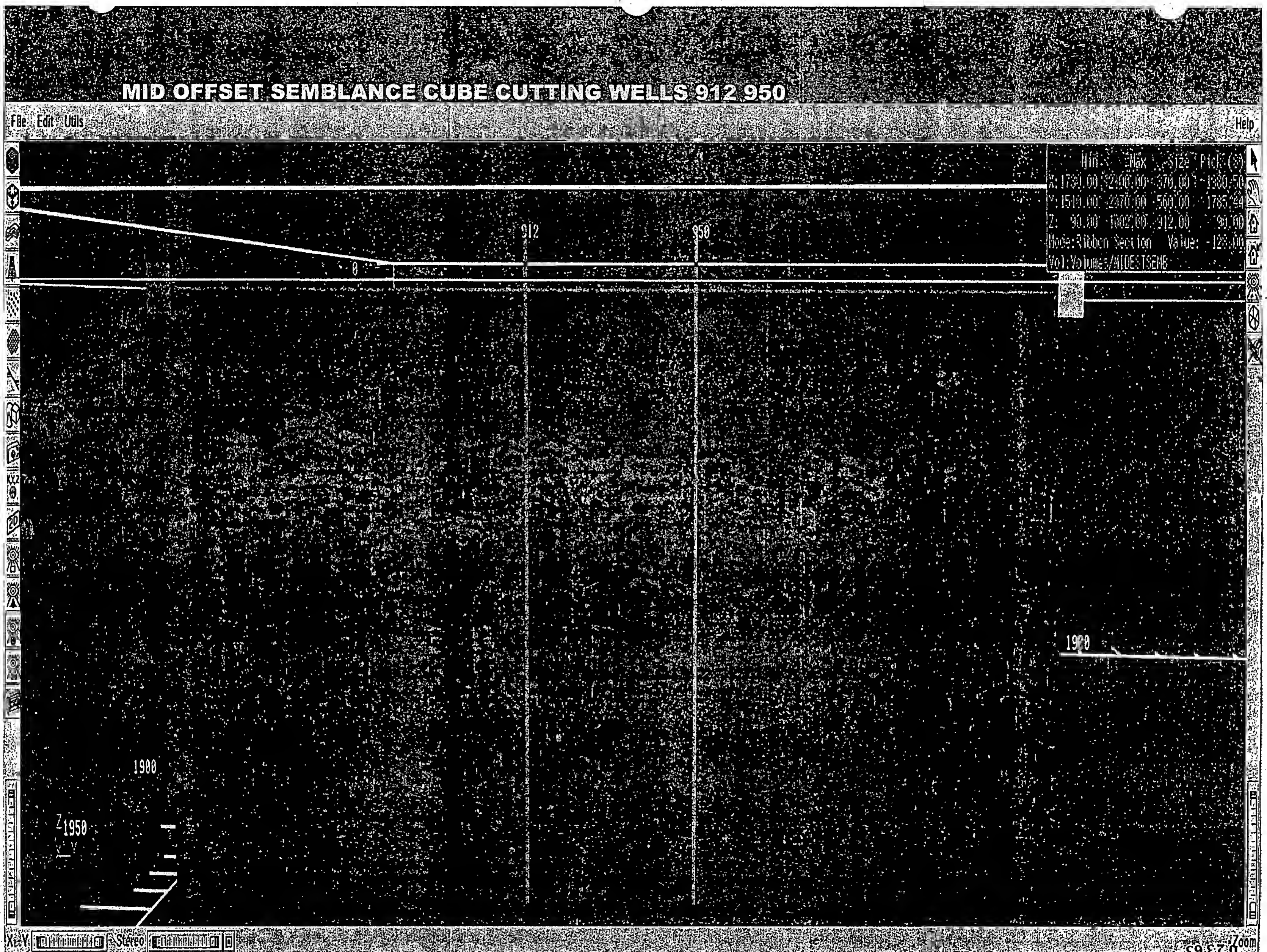

MID OFFSET SEMBLANCE CUBE CUTTING WELLS 912 950
File
Edit
Utils
Help
912
950
0
1900
1900
1950
Stereo
Zoom
Mode: Ribbon Section

Figure 21

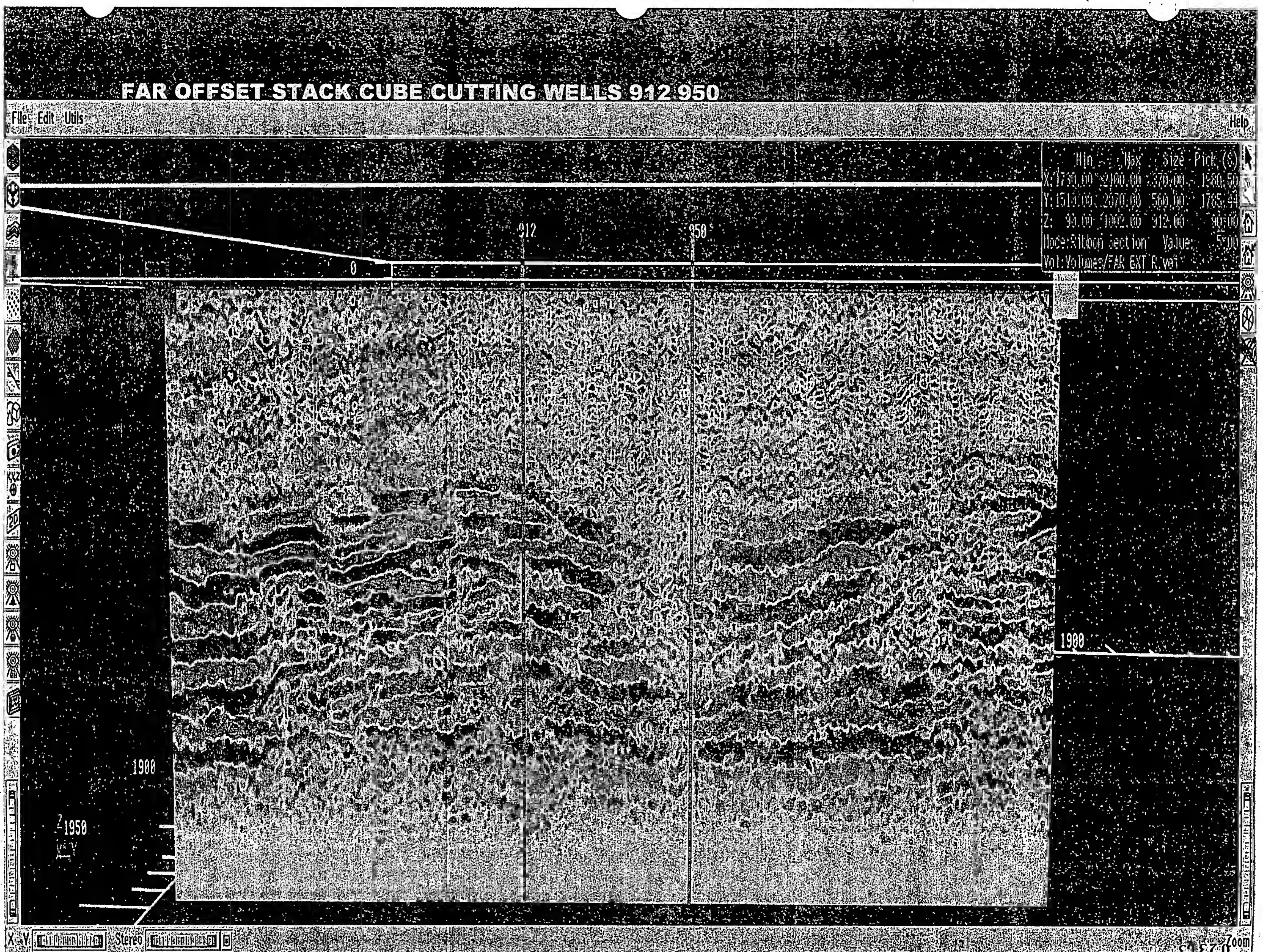
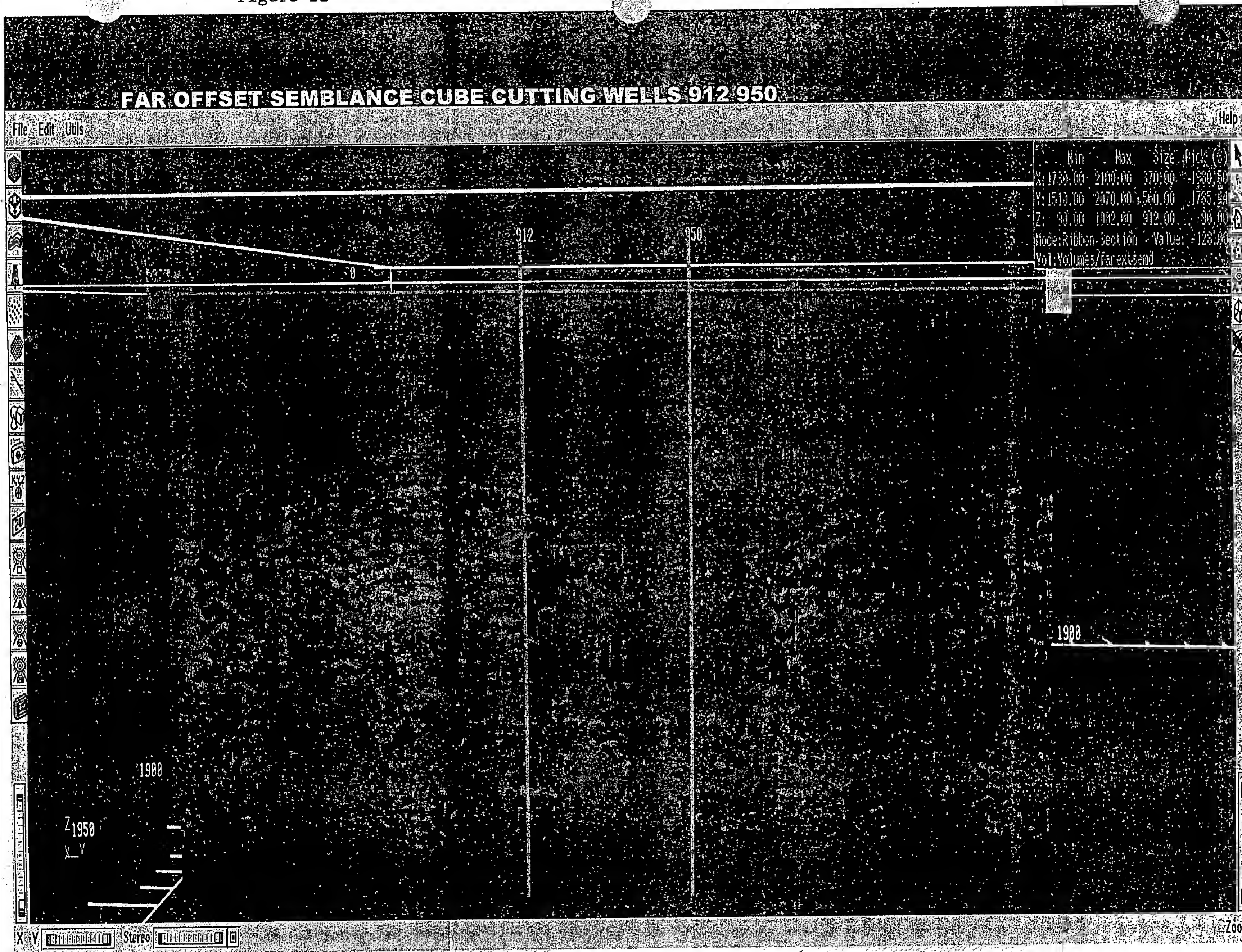

FAR OFFSET STACK CUBE CUTTING WELLS 912 950
File Edit Utils
Help
Min Max Size Pick (S)
X:1730.00 2100.00 370.00 1880.50
Y:1510.00 2070.00 560.00 1785.44
Z: 90.00 1002.00 912.00 90.00
Mode:Ribbon Section Value: 5.00
Vol:Volumes/FAR EXT R.vol
0
912
950
1900
1900
1950
Stereo
Zoom

Figure 22



FAR OFFSET SEMBLANCE CUBE CUTTING WELLS 912 950
File
Edit
Utils
Help
Min
Max
Size
912
950
1900
Z 1950
X_Y
Stereo
Zoom

Figure 23

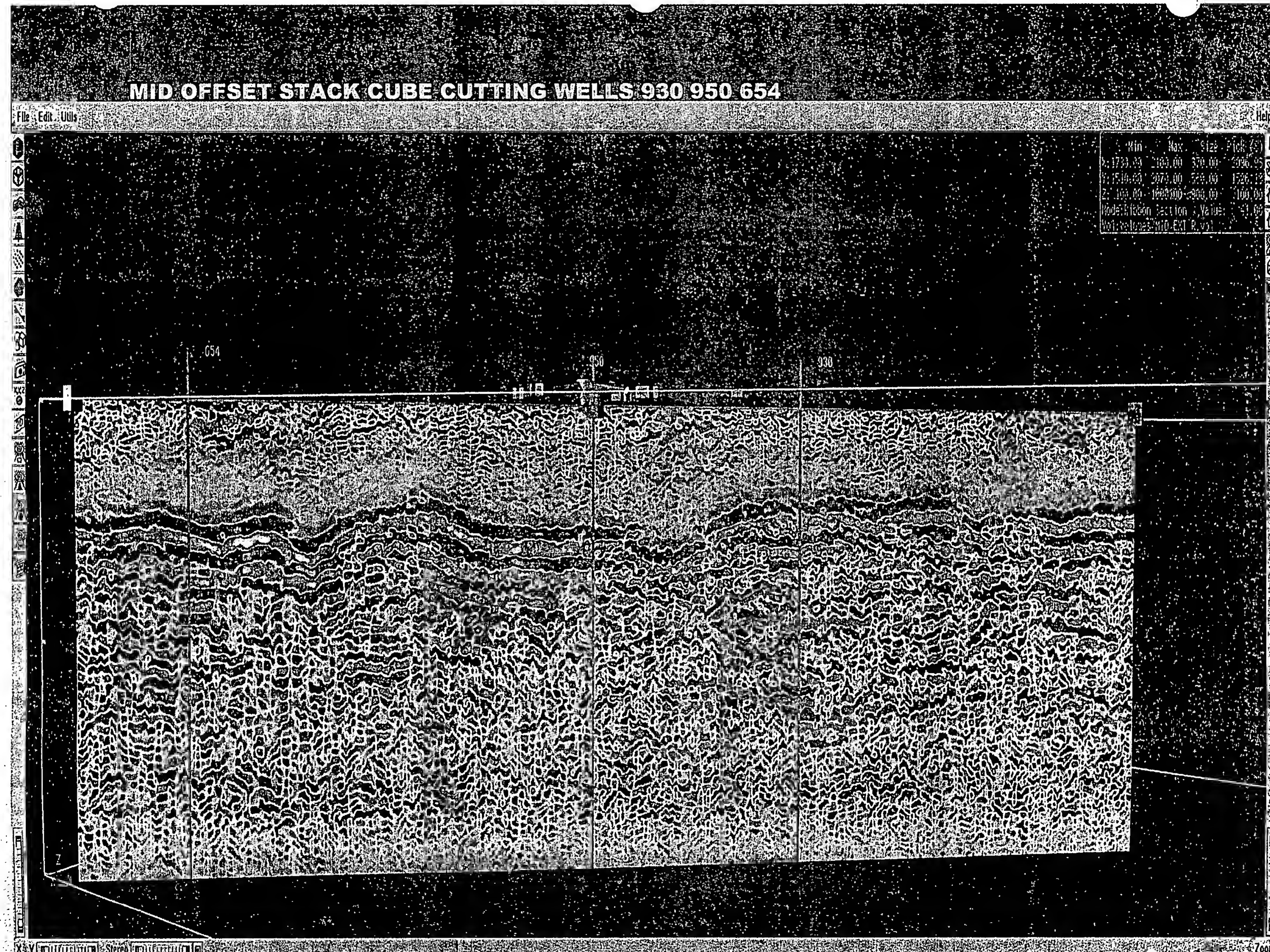


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Figure 24

MID OFFSET SEMBLANCE CUBE CUTTING WELLS 930 950 654

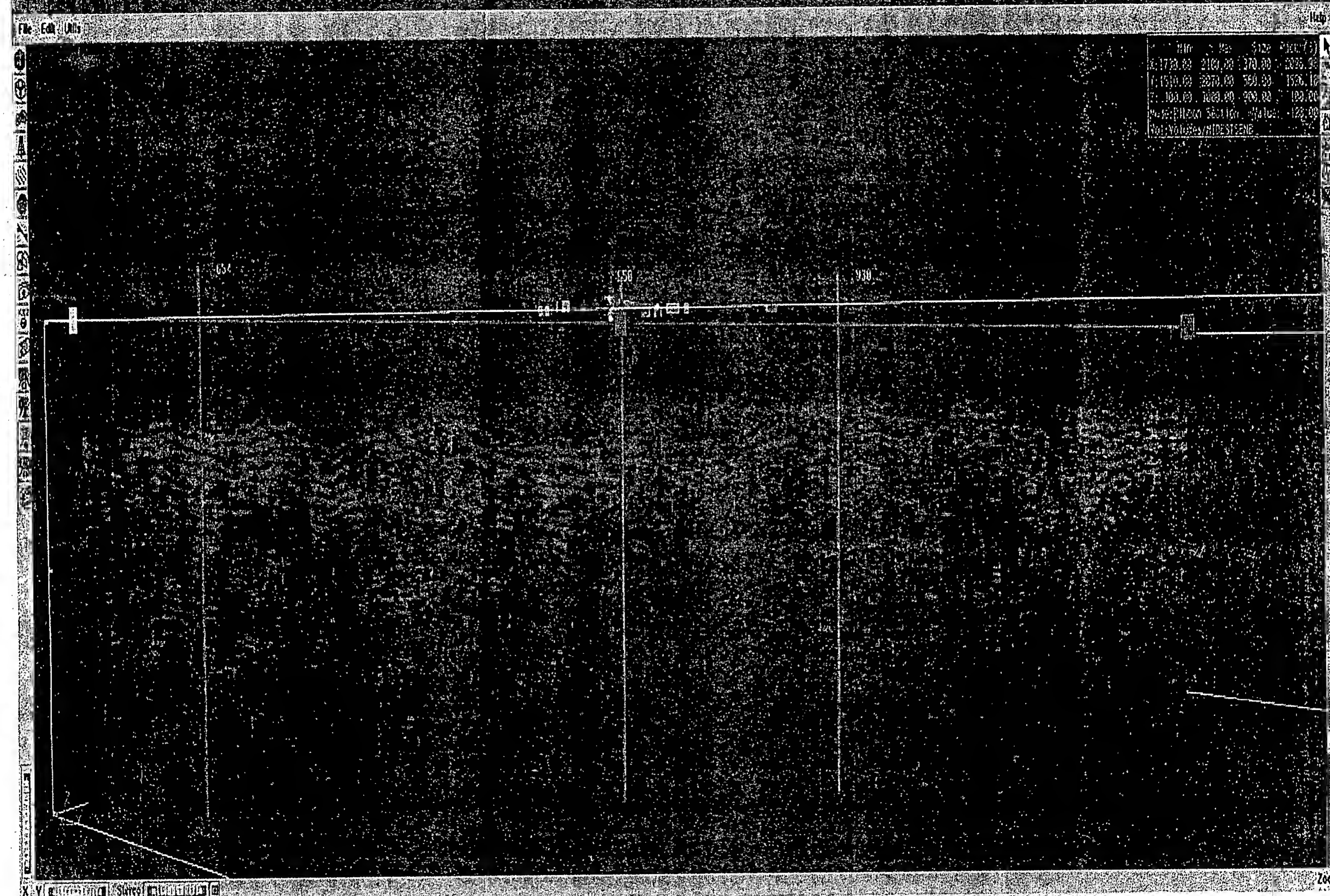

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Figure 25

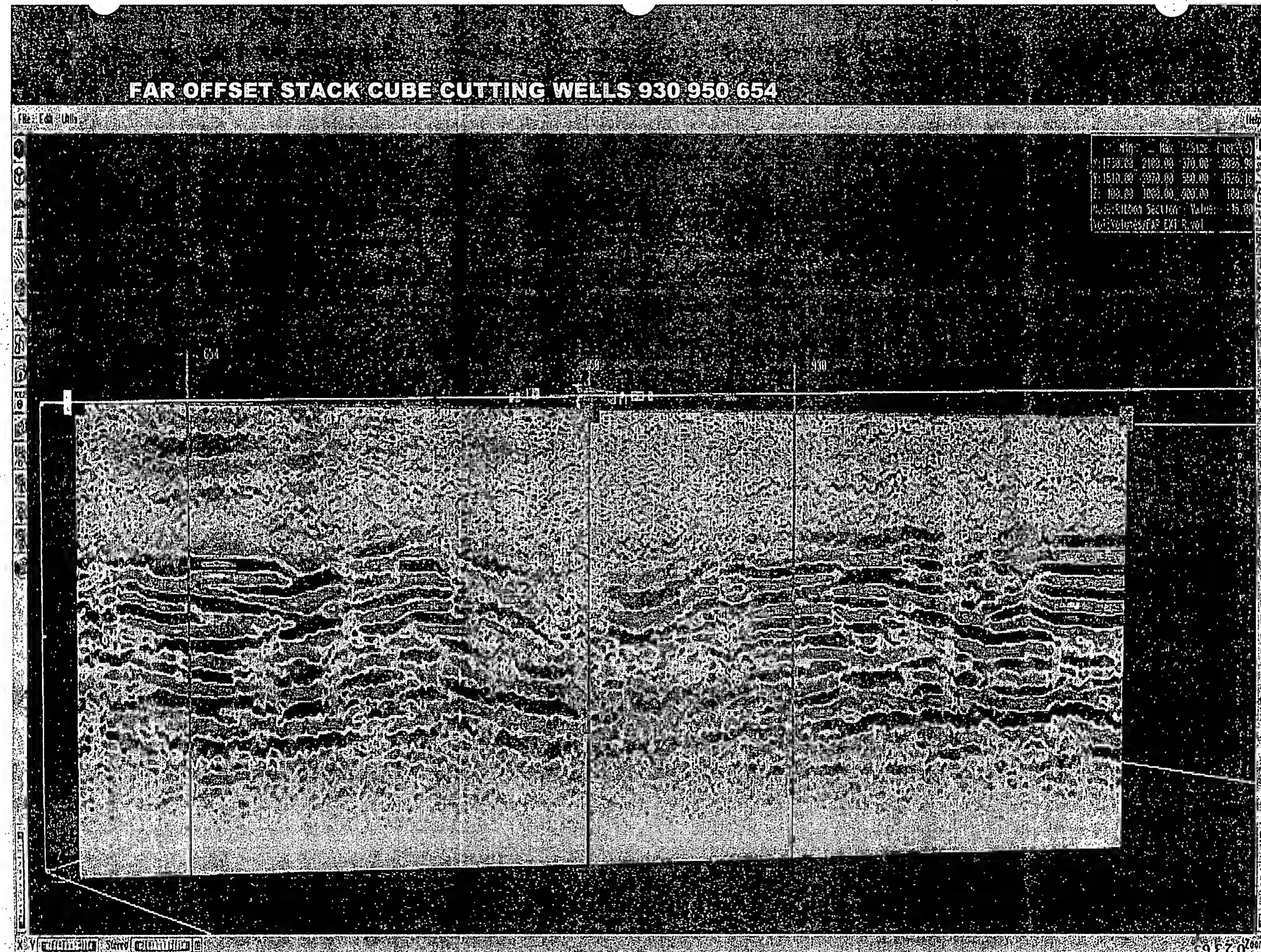
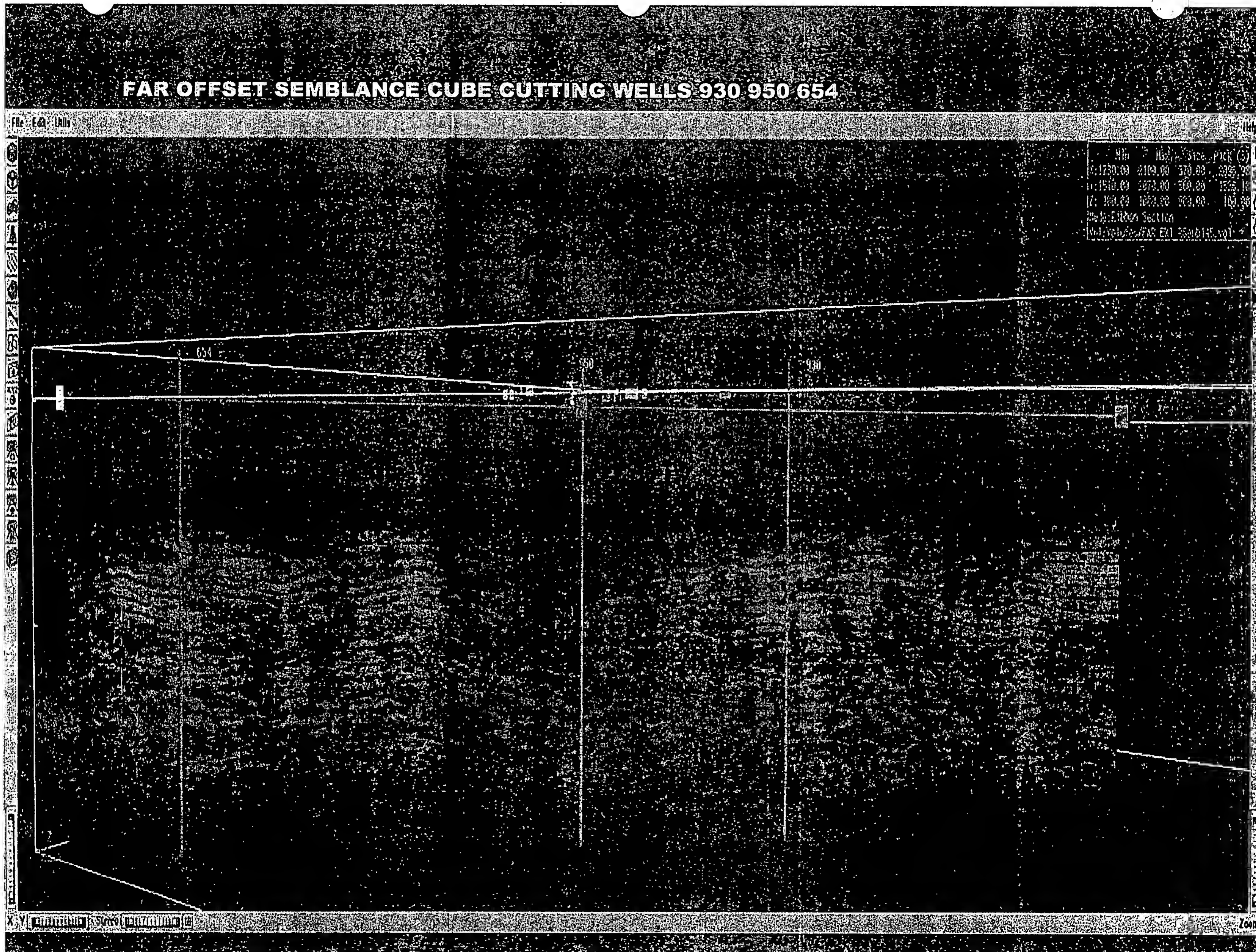

FAR OFFSET STACK CUBE CUTTING WELLS 930 950 654
File Edit Utils
Help
654
950
930
Stereo
Zoom

Figure 26


FAR OFFSET SEMBLANCE CUBE CUTTING WELLS 930 950 654
File
Edit
Utils
Help
654
950
930
Stereo
Zoom

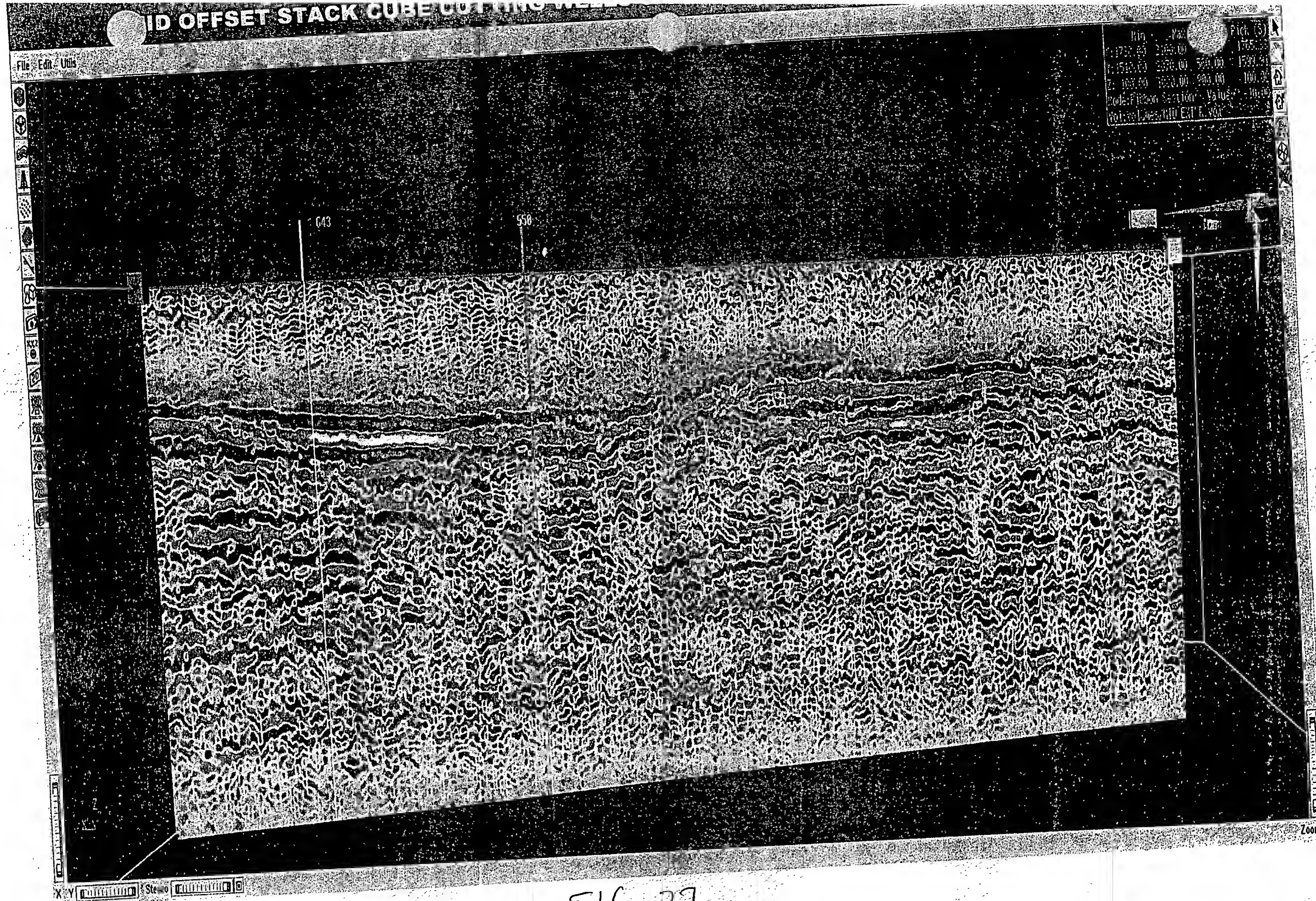


FIG. 27

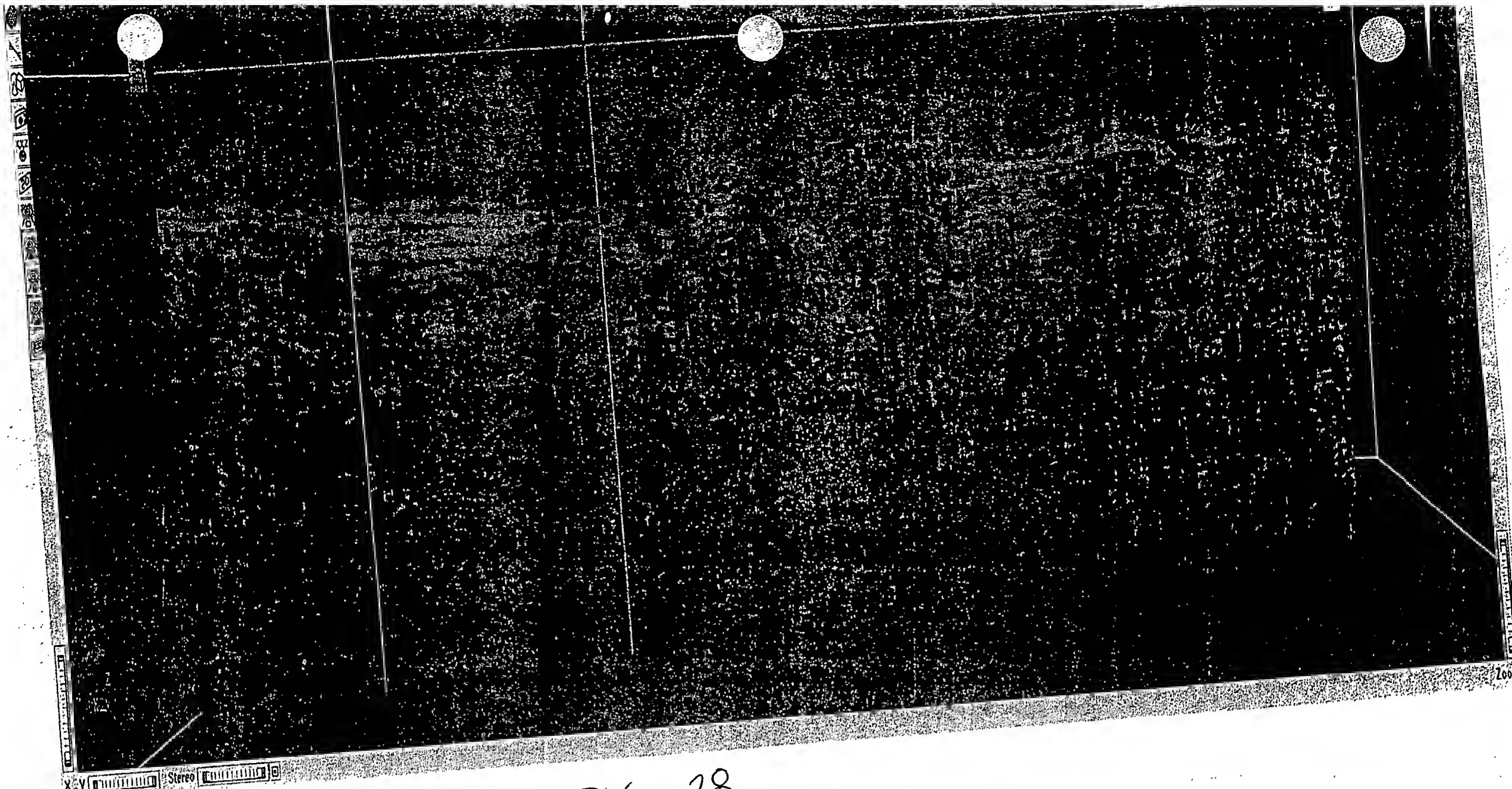


FIG. 28

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Figure 29

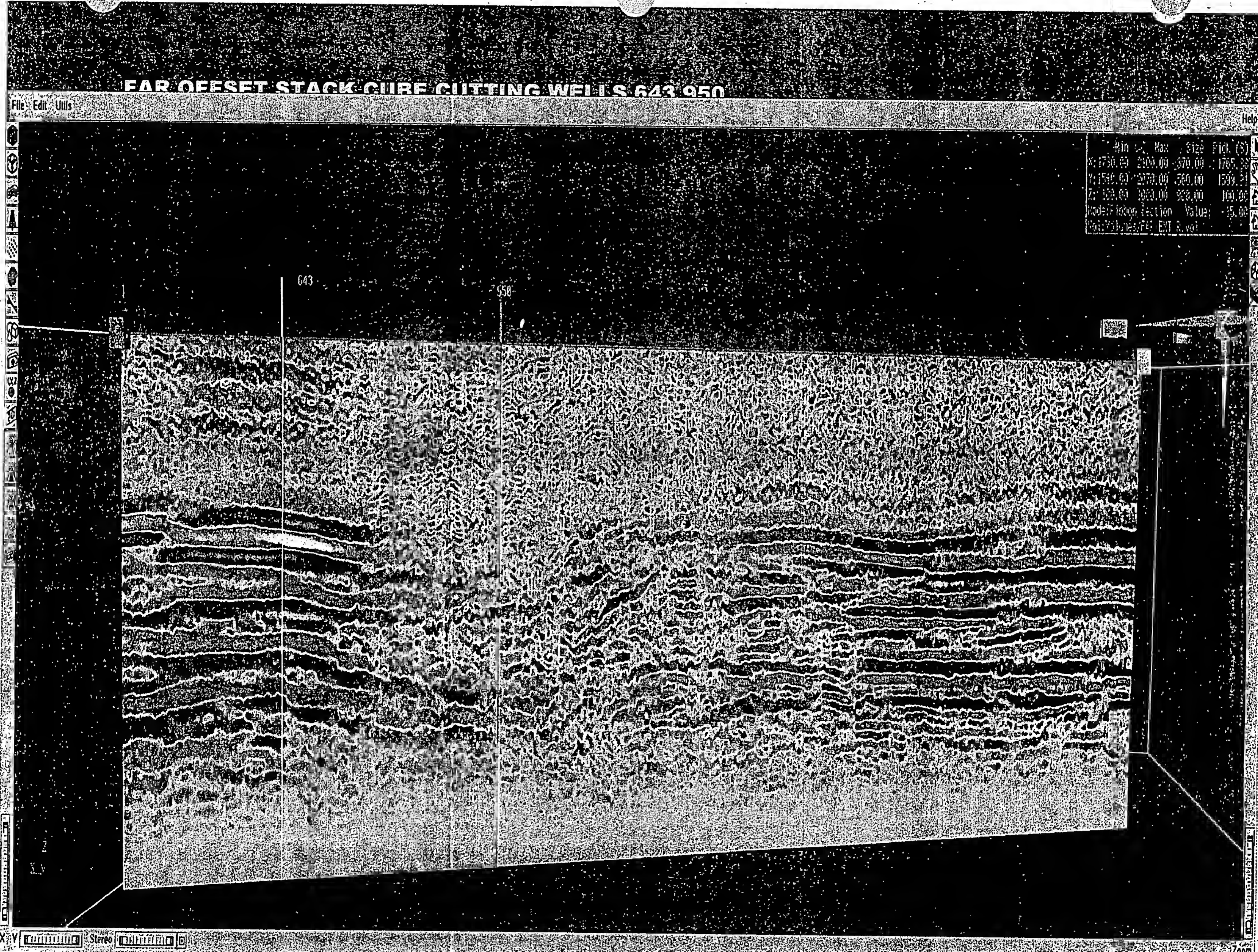
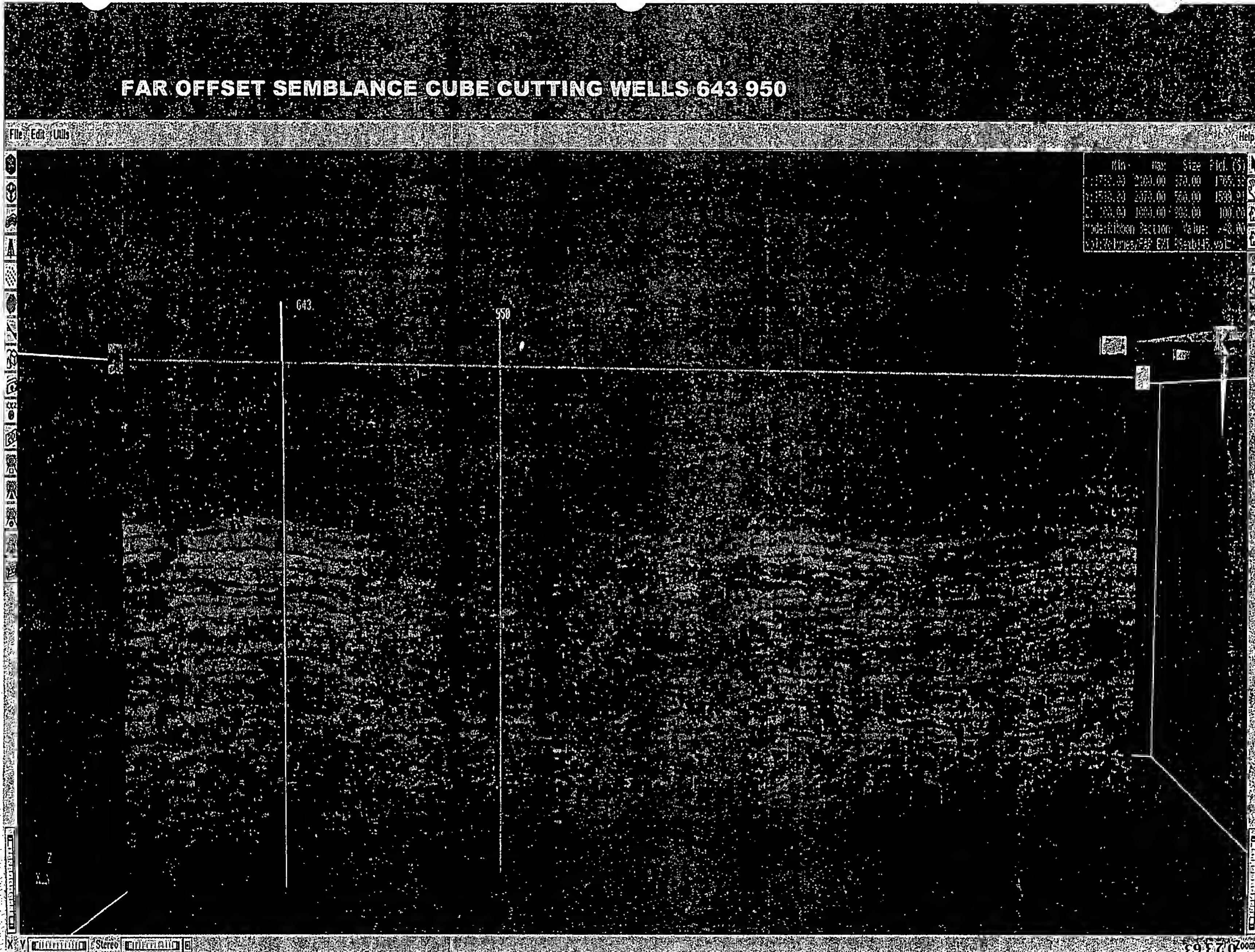

FAR OFFSET STACK CUBE CUTTING WELLS 643 950
File Edit Utils
Help
643
950
Stereo
Zoom

Figure 30


FAR OFFSET SEMBLANCE CUBE CUTTING WELLS 643 950
File Edit Utils
Help
643
950
Stereo
Zoom

Preliminary Conclusions

- Resolution and detection of karst features is limited by the bin sizes in our production seismic data. We believe that a targeted acquisition test over a small area could yield improved prediction accuracy.
- Potential benefits to drilling are reduced mechanical risks and costs to Saudi Aramco in well planning & execution in the Ghawar field.
- This is a fast procedure.

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FIG 31